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THE GEORGE C. MARSHALL SPACE FLIGHT CENTER'S 14 X 14-INCH TRISONIC WIND TUNNEL TECHNICAL HANDBOOK

By Erwin Simon
Aero-Astrodynamics Laboratory

November 5, 1971

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

NOTICE

Because of a waiver initiated and signed in compliance with NASA Policy Directive (NPD) 2220.4, para. 5-b, the International System of Units of measurement has not been used in this document.

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16. ABSTRACT

This handbook is intended to be an informative presentation of the George C. Marshall Space Flight Center's 14 x 14-Inch Trisonic Wind Tunnel capabilities to the potential user. The information presented allows more thorough preliminary test planning to be carried out.

The following items are presented to illustrate the capabilities and operation of the tunnel.

Facility Description

Performance and Operational Characteristics

Model Design Criteria

Instrumentation and Data Recording Equipment

Data Processing and Presentation

Preliminary Test Information Required.

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E D Geissler

E. D. Geissler
Director, Aero-Astrodynamics Laboratory

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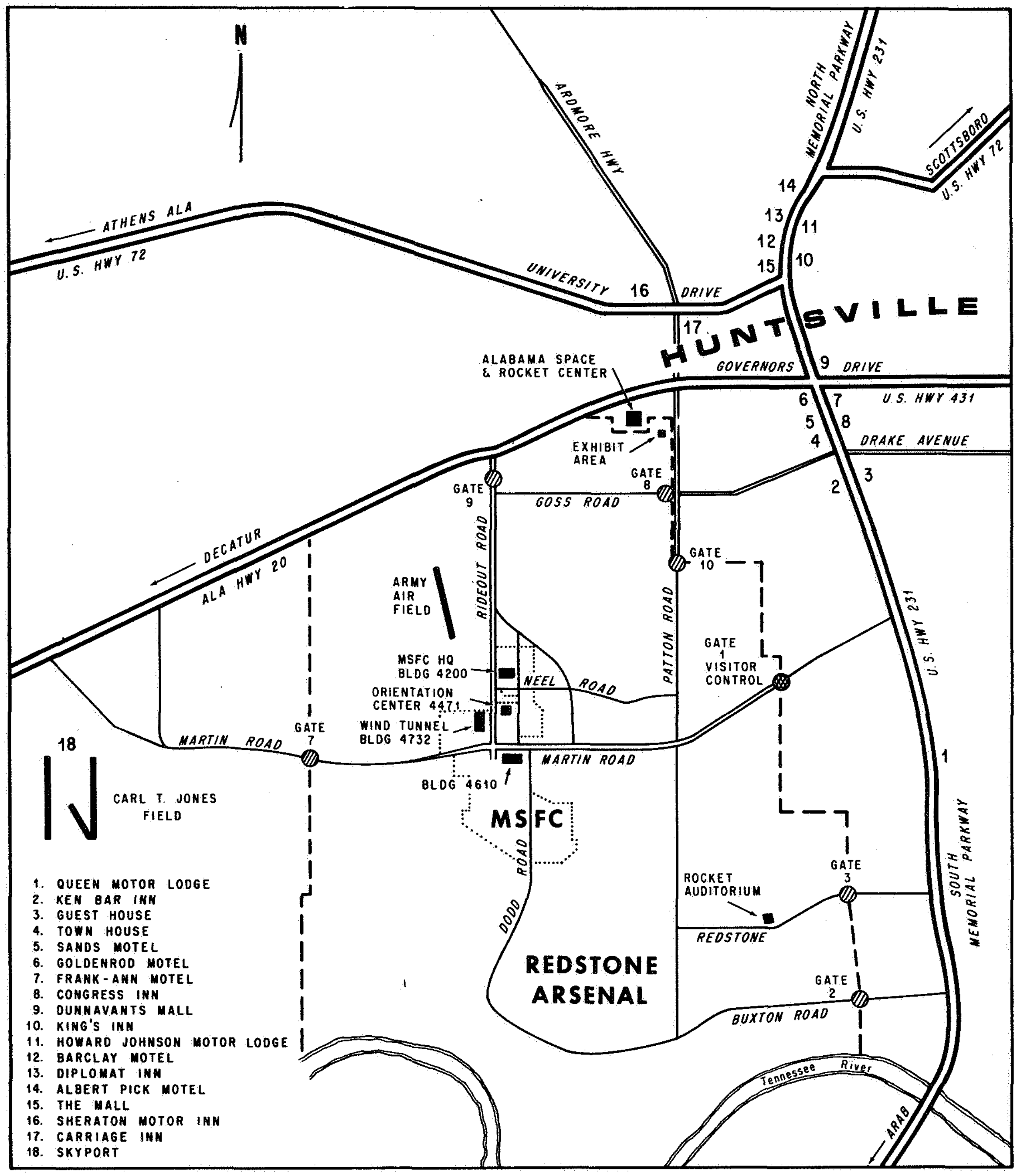


FIGURE 1. AREA MAP

THE GEORGE C. MARSHALL SPACE FLIGHT CENTER'S 14 x 14-INCH TRISONIC WIND TUNNEL TECHNICAL HANDBOOK

SUMMARY

This report is a description of the 14 x 14-Inch Trisonic Wind Tunnel facility at the Marshall Space Flight Center and is published as a handbook for the potential user of the facility who is not otherwise familiar with its operation. The following items are presented to illustrate the capabilities and operation of the tunnel: (1) facility description, (2) performance and operational characteristics, (3) model design, (4) instrumentation and data recording equipment, (5) data processing and presentation, and (6) preliminary test information required.

INTRODUCTION

Marshall Space Flight Center and its predecessor organization have traditionally followed the philosophy that the existence of an aerodynamic backyard facility is essential to the efficient fulfillment of the center's mission. The concept requires that the facilities be reasonably small, inexpensive in capital investment and operation, very flexible and efficient, and operable by a small crew. Such facilities provide the center with a quick response capability during conceptual design phases as well as in emergency problems during flight testing. Another capability provided is the opportunity for inexpensive screening, preliminary study, and technique development work, which are uneconomical in large outside facilities. Further, these facilities give the center a degree of responsiveness to its special and sometimes tedious problems that cannot be obtained from outside organizations due to human factors such as familiarity with the problem, enthusiasm, and motivation, all of which are not easily transferred from one organization to another. The final contribution is to afford the center's personnel the opportunity to maintain and advance their technical capability, a necessity in the proper formulation and direction of the center's programs. This facility philosophy has proved to be quite successful in the Redstone, Jupiter, Juno I, Juno II, Pershing, and Saturn programs.

The 14 x 14-Inch Trisonic Wind Tunnel described in this report is an important part of this backyard capability. It was designed and constructed during the period 1954-1955 and became operational in early 1957.

Other facilities include a 7 x 7-Inch Supersonic Wind Tunnel, an Impulse Base Heating Facility for high altitude base heating, a Low Density Tunnel, a Thermal-Acoustic Jet Facility and most recently a High Reynolds Number Facility.

The 14-inch tunnel is operated and maintained through a contract with Northrop Space Laboratories under supervision of NASA personnel of Aero-Astrodynamics Laboratory, Aerophysics Division. Although generally used in support of NASA-MSFC programs, the tunnel is available to other government agencies.

This handbook is published with the hope that the user will have a better understanding of the 14 x 14-Inch Trisonic Wind Tunnel and its operation. This will allow the reader to more thoroughly plan and follow through with a test program.

Because the information presented in the handbook is subject to change, final verification with the tunnel staff is desirable before any detailed planning is undertaken. Inquiries may be directed to

Chief, Gas Dynamics Section
Experimental Aerophysics Branch
Aerophysics Division
Aero-Astrodynamics Laboratory, NASA-MSFC
Bldg. 4732
Marshall Space Flight Center, Alabama 35812

TUNNEL SUMMARY

The 14 x 14-Inch Trisonic Wind Tunnel at the George C. Marshall Space Flight Center (MSFC) is a trisonic blowdown tunnel with interchangeable test sections. The tunnel is located in Building 4732 as shown in the Area Map in Figure 1. The building layout is shown in Figure 2.

Complete in-house support is supplied by a competent technical staff, a complete machine shop, an electromechanical staff (electronics and model design), and a photographic laboratory.

I. Tunnel Specifications

Type of Tunnel	Blowdown to atmosphere or vacuum
Test Section Size	14 x 14 x ~ 20 inches

Nozzles	The transonic tunnel utilizes interchangeable fixed contour blocks. The supersonic section uses fixed contour plates positioned by hydraulic screw jacks.
Mach Number Range	0.30, - 1.3, 1.44, 1.93, 2.5 (transonic section) 2.75 to 5.00 (supersonic section)
Dynamic Pressure Range	2 to 20 psi
Reynolds Number Range	1 to 18 million/ft
Stagnation Temperature	Ambient to 200°F; normally 100°F
Run Time	1.5 to 2.0 minutes (transonic) 45 to 50 seconds (supersonic)
Air Storage	6000 cubic feet at 515 psia and 100°F
Vacuum Storage	42,000 cubic feet at 0.1 psia
Recharge Time	5-10 minutes nominally for transonic and 15-20 minutes nominally for supersonic. Supplemental charging may be done with 3500 psi plant air when needed.

II. Data System

Angle of Attack	-10 to +10 degrees with added range provided by offset stings up to 90°
Data Channels	12 data channels with 10 available to the user
Data Computation	On-site computer with setups for pressure and force programs.

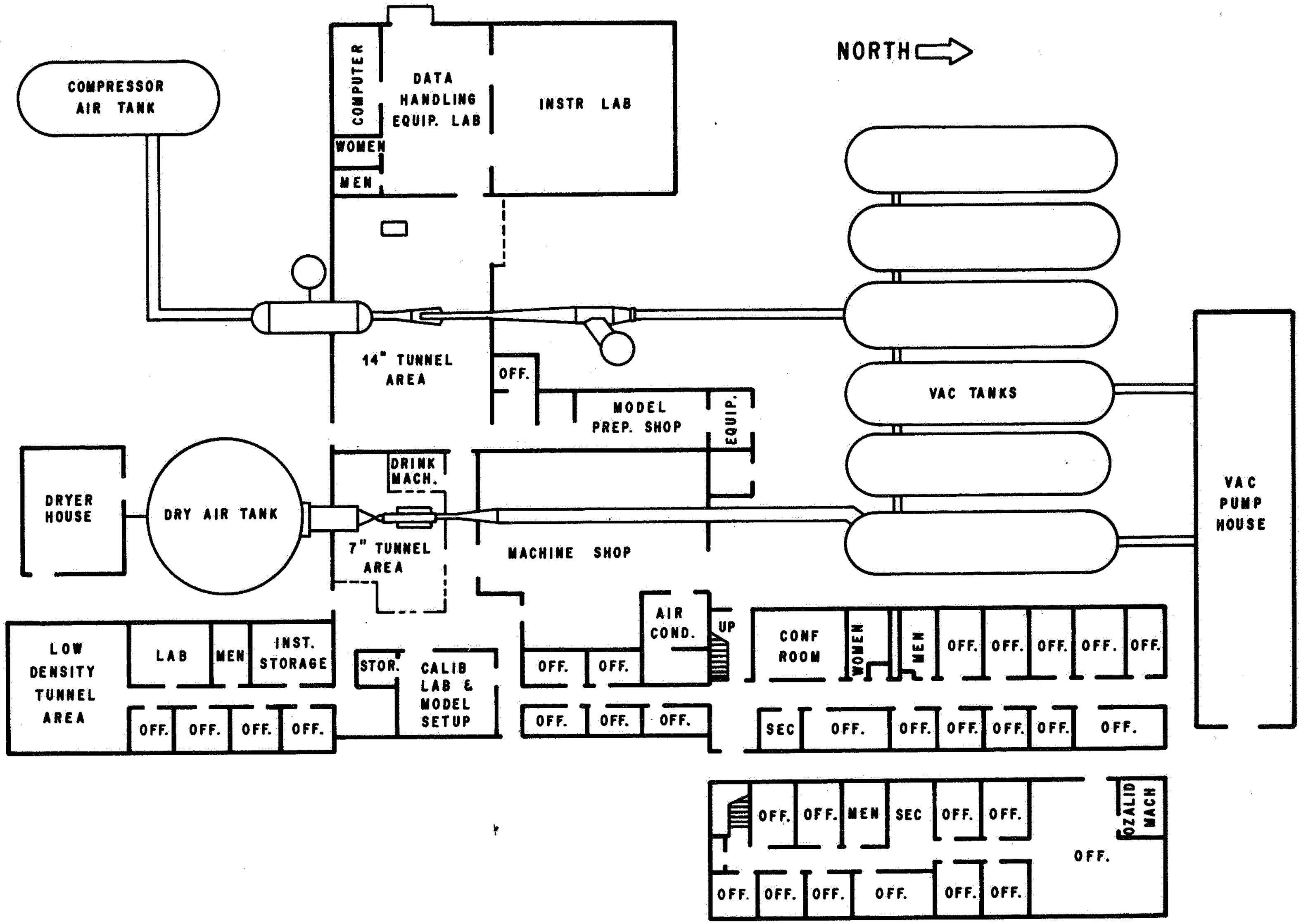


FIGURE 2. LAYOUT OF WIND TUNNEL BUILDING

DESCRIPTION OF TUNNEL

The tunnel is an intermittent trisonic blowdown tunnel operated from pressure storage to vacuum or atmospheric exhaust. The test section measures 14 x 14 inches in two of the interchangeable test sections. The transonic section provides for Mach numbers of 0.20 through 2.50 and the supersonic section provides for Mach 2.75 through 5.00.

Air is supplied to a 6000 cubic foot storage tank at -40°F dew point and 500 psia. The compressor is a three-stage reciprocating unit driven by a 1500 hp motor.

The tunnel flow is established with a servo-controlled gate valve. Air from the control valve flows through the valve diffuser into the stilling chamber where the air can be heated up to 200°F. Air then flows into the test section which contains the nozzle blocks and test area.

Speeds are varied in the subsonic range by a controllable diffuser, in the transonic range by perforated tunnel walls, in the low (1.5-2.5) supersonic range by interchangeable nozzle blocks, and in the higher (2.75-5.00) supersonic range by tilting fixed contour nozzle blocks.

The transonic section has variable porosity walls that allow for optimum wave cancellation in the transonic flow region.

Downstream of the test section is a hydraulically controlled sector that provides for angles of attack of ±10° with various offsets extending the pitch limits to 90°.

The variable diffuser, with its movable floor and ceiling panels, is the primary means for controlling the subsonic speeds; it also allows for more efficient supersonic runs. The sector assembly and diffuser telescope to allow easy access to the model and test section.

The tunnel flow is then exhausted through an acoustically damped tower to atmosphere or into the vacuum field of 42,000 cubic feet. The tanks are evacuated by five vacuum pumps driven by a total of 500 hp.

Data are recorded by a solid state digital data acquisition system. The digital data are transferred to punched cards during the run to be reduced later to proper coefficient form by a computer.

The tunnel components and performance are discussed in more detail later in the report.

Illustrations are presented to further familiarize the reader and potential tunnel user with the building and tunnel test area layouts. All figures have the major areas defined and are self-explanatory.

Figure 2 is a floor plan of Building 4732 showing the location of the 14 x 14-Inch Trisonic Wind Tunnel. Figure 3 is a graphic illustration of the complete tunnel circuit and a photograph showing the tunnel test area.

Test Section. Three interchangeable test sections, the transonic, the supersonic, and the special test sections, provide a wide range of aerodynamic testing capability. These test sections are shown in cutaway drawings in Figure 4.

The transonic test section, the perforated wall type, covers a Mach number range from 0.3 to 2.50. The perforated walls use 5/32-inch diameter holes which are slanted 30° with respect to the flow direction. The porosity of the walls may be varied remotely by the use of a double wall arrangement from a minimum of 0 percent to a maximum of 5.4 percent. This feature makes possible better data accuracy in the Mach number range from 1.00 to 1.30 than would be possible with fixed porosity walls.

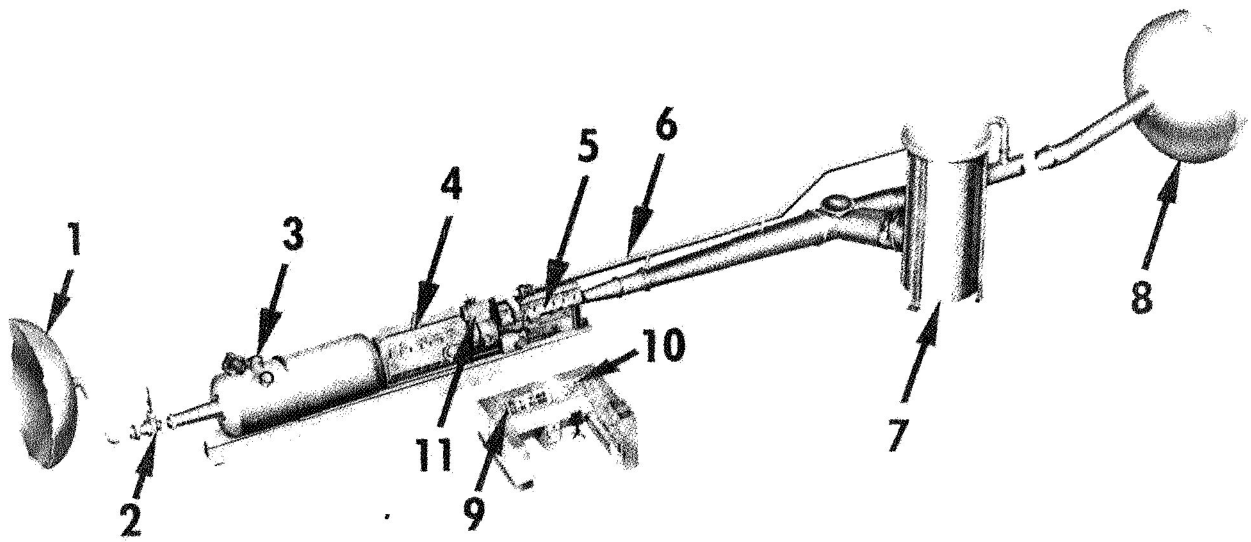
The Mach numbers between 0.3 and 0.90 are obtained by using a controllable diffuser. The range from 0.95 to 1.30 is achieved through the use of plenum suction and the perforated walls. Mach numbers of 1.44, 1.93 and 2.50 are produced by interchangeable sets of fixed contour nozzle blocks.

An automatic Mach controller maintains a constant Mach number in the transonic range by controlling plenum suction. The controller compensates for Mach variations such as those caused by a model pitch cycle.

The supersonic test section produces Mach numbers between 2.74 and 4.96 in approximate 0.25 increments. This is accomplished by a set of fixed contour blocks which can be tilted and translated automatically by hydraulic means.

The special test section was built for the purpose of investigating the base flow phenomena associated with multi-engine boosters. This test section uses a plug-type nozzle to produce an annular flow field of a desired supersonic Mach number range. Mach numbers from 1.5 through 3.5 are obtained by translating the outer nozzle wall. The vehicle base or model is an extension of the nozzle plug. Internal engine flow may be simulated cold by using a 3500 psi air system.

Diffuser. The diffuser which is located immediately downstream of the model support system is remotely adjustable from the control console and is actuated by two hydraulically driven screw jacks. The throat opening may be varied from fully open to fully closed and provides the primary means for speed control in the range of Mach numbers from 0.3 to 0.9.



1. 500 psi Air Storage
2. Control Valve
3. Settling Chamber and Heater
4. Test Section
5. Controllable Diffuser
6. Plenum Section Vacuum Line
7. Atmospheric Exhaust Tower
8. Vacuum Field
9. Tunnel Control Panel
10. Tunnel Data System Panel
11. Pressure Switch Panel
12. Schlieren Receiver

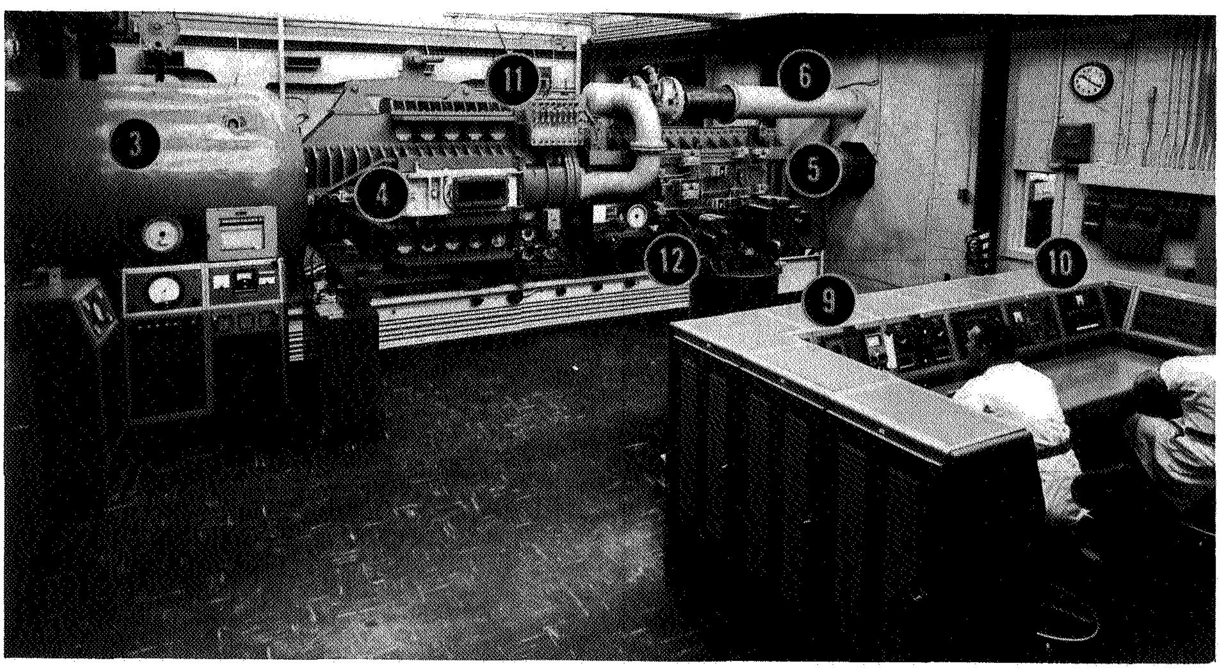


FIGURE 3. 14 x 14-INCH TUNNEL AND CONTROL AREA

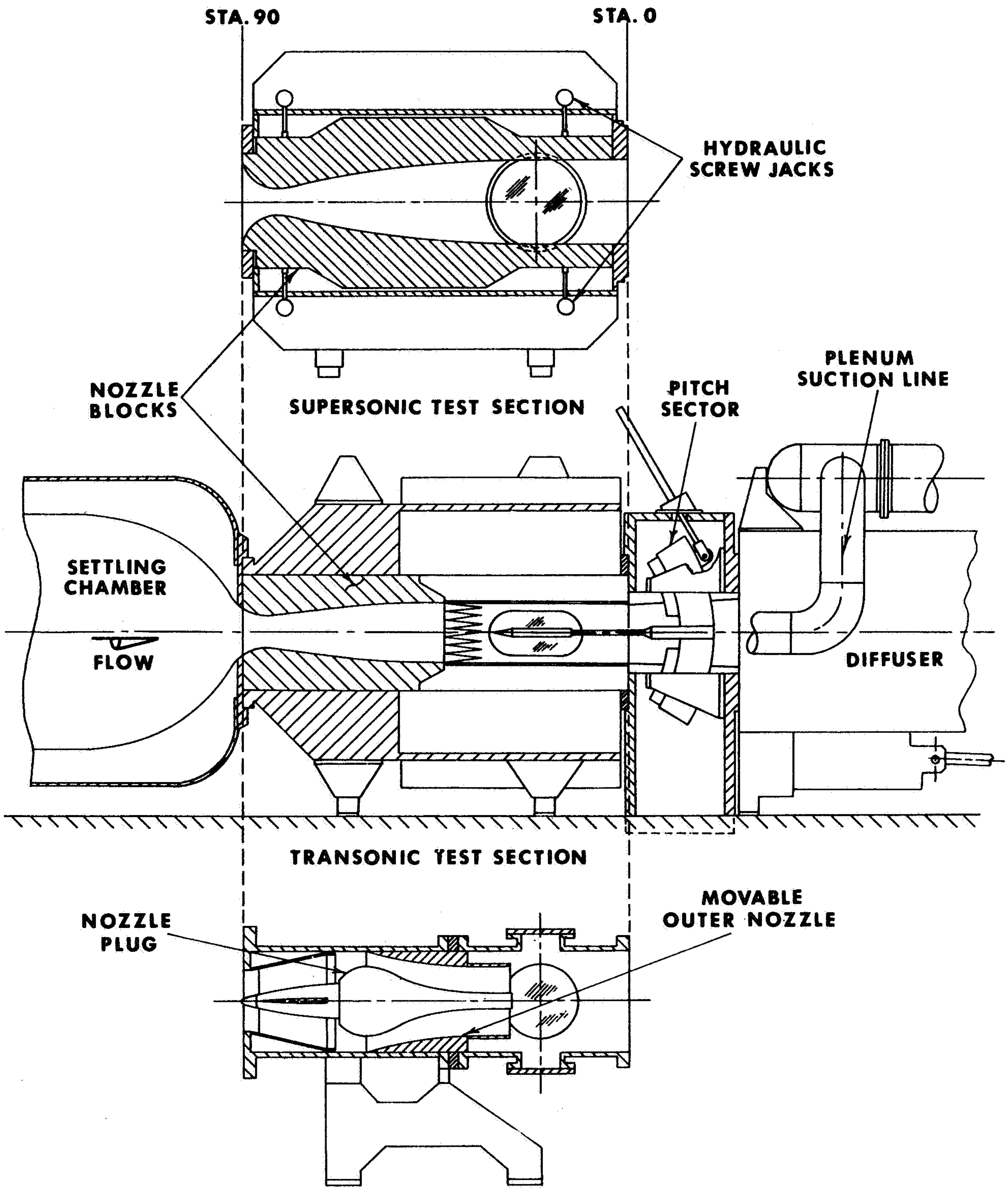


FIGURE 4. INTERCHANGEABLE TEST SECTIONS

Air Supply System

Air Compressor and Vacuum Pumps. Air is compressed by a reciprocating three-stage air compressor (Figure 5a) driven by a 1500 hp electric motor. The rated capacity of the system is 4500 scfm at a delivery pressure of 500 psig. The air is passed from the third stage through an aftercooler, and an oil absorber to a chemical dryer which reduces the dew point to -40°F or lower. From the dryer, the air is delivered to a 6000 cubic foot cylindrical storage tank. The compressor pumping curve is shown in Figure 5b.

The vacuum system consists of five vacuum pumps evacuating six interconnected tanks with a combined volume of 42,000 cubic feet. The pumps (Figure 6a) are driven by motors totaling 500 hp and have a combined capacity of 10,200 cfm at atmospheric intake pressure. The vacuum pumping rate is given in Figure 6b.

Valves. Three valves are located between the storage tank and the test section. The first valve immediately following the storage tank is a manual gate valve which is generally used during maintenance of the tunnel circuit. Downstream is the safety valve, which is located next to the main control valve. The main control valve is a hydraulically operated gate valve which was designed and fabricated at MSFC. It has the unique features of low wear, few parts, and yet providing a positive seal in the closed position. The servo system which positions the valve is actuated from the tunnel operator's control panel. Control signals for the valve are obtained from the error signal which is in turn obtained from the comparison of the actual stagnation pressure and a stagnation pressure "setpoint." The control valve opens and closes as required to compensate for tank pressure drop and other pressure fluctuations. Two valves are necessary for choosing exhausting conditions. The auxiliary vacuum line contains a 30-inch butterfly valve, and a 48-inch butterfly valve controls the atmospheric exhaust.

Tunnel Circuit. Immediately downstream of the control valve is a conical diffuser which contains four shock holders that help prevent pressure fluctuations resulting from shock oscillations. The settling chamber is approximately six feet in diameter and houses a tube-type, counter-flow heat exchanger using hot water. Downstream of the heat exchanger are two three-mesh flow straighteners and three twenty-mesh flow damping screens.

The settling chamber is protected from overpressure by three 12-inch diameter rupture discs, set at 120 psia. Also mounted on the settling chamber is a pressure relief valve described in a later section. Plenum suction for transonic testing is controlled by the tunnel operator and is used to make final Mach number adjustments.

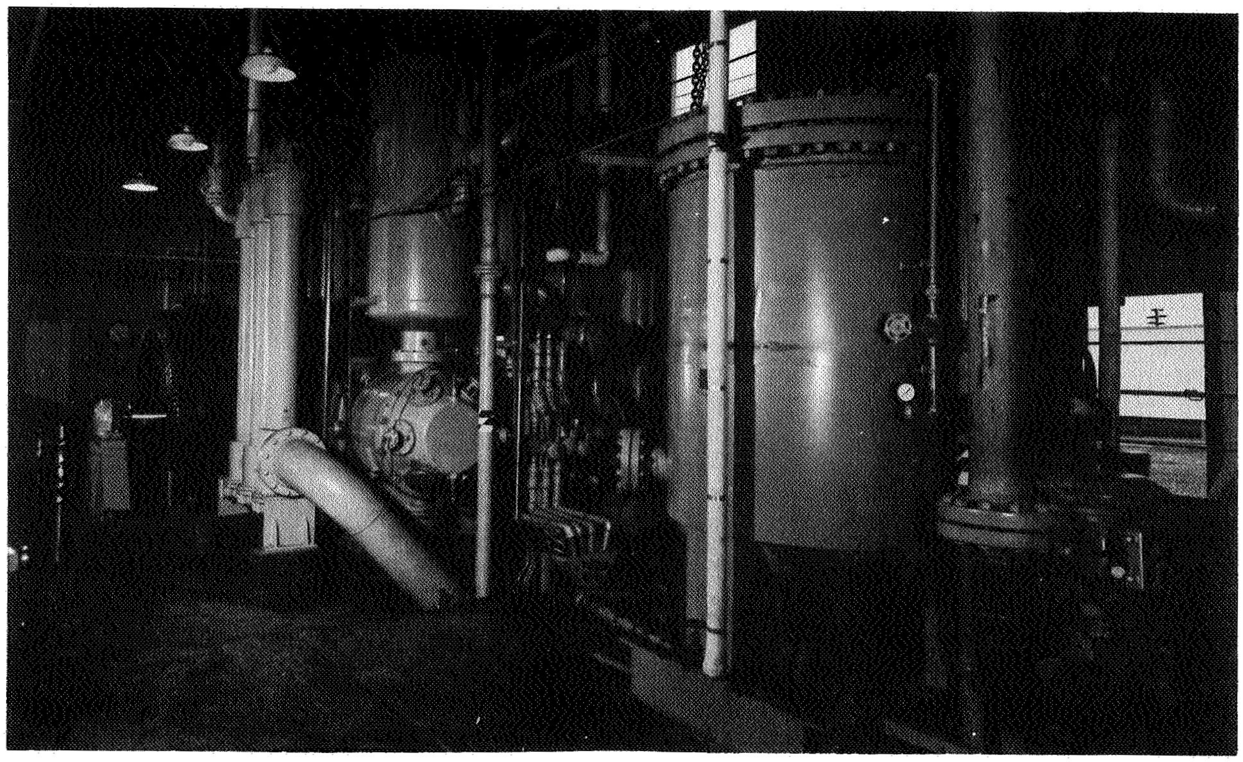


FIG. 5a. COMPRESSOR

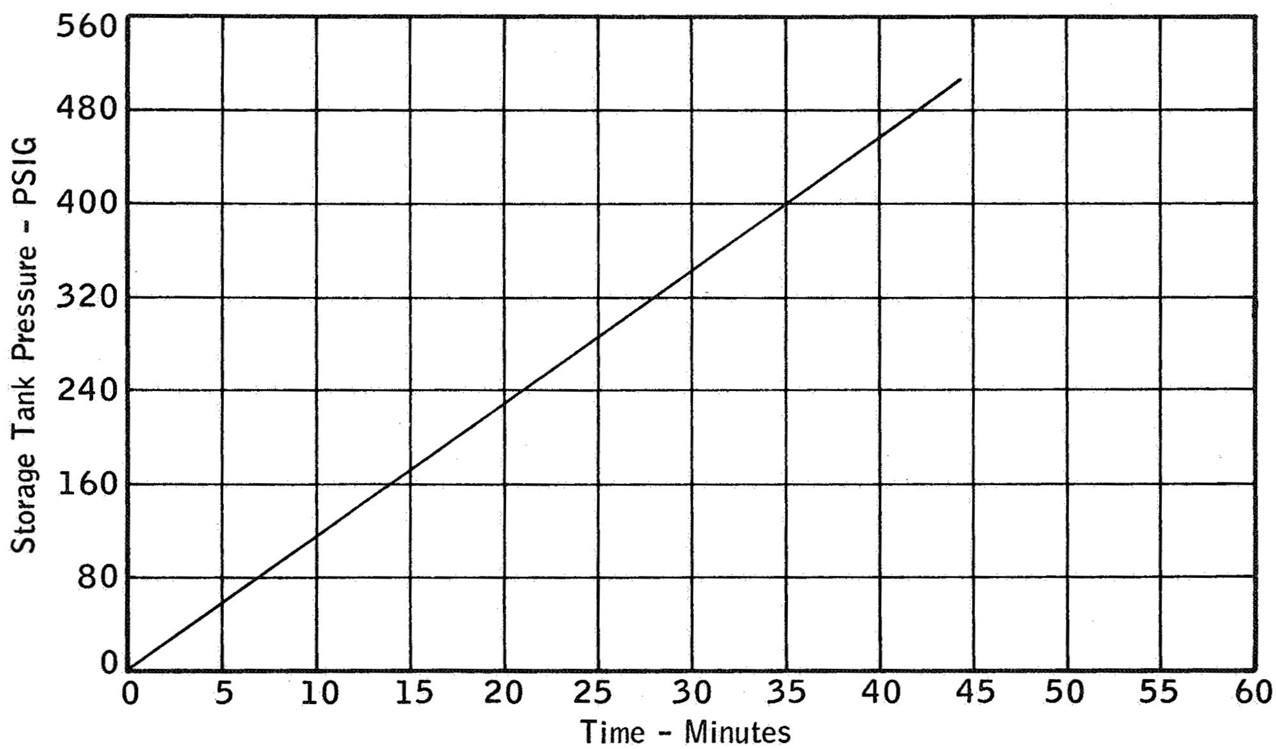


FIG. 5b. COMPRESSOR PUMPING SCHEDULE

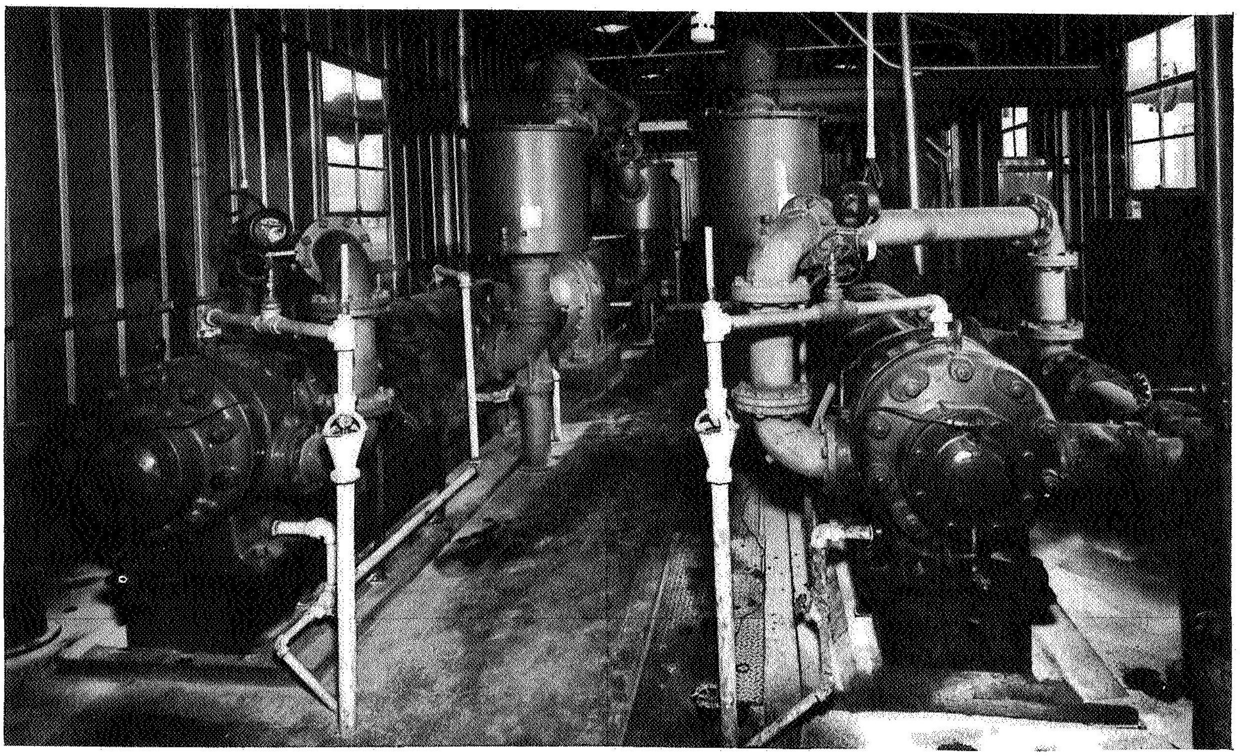


FIG. 6a. VACUUM PUMPS

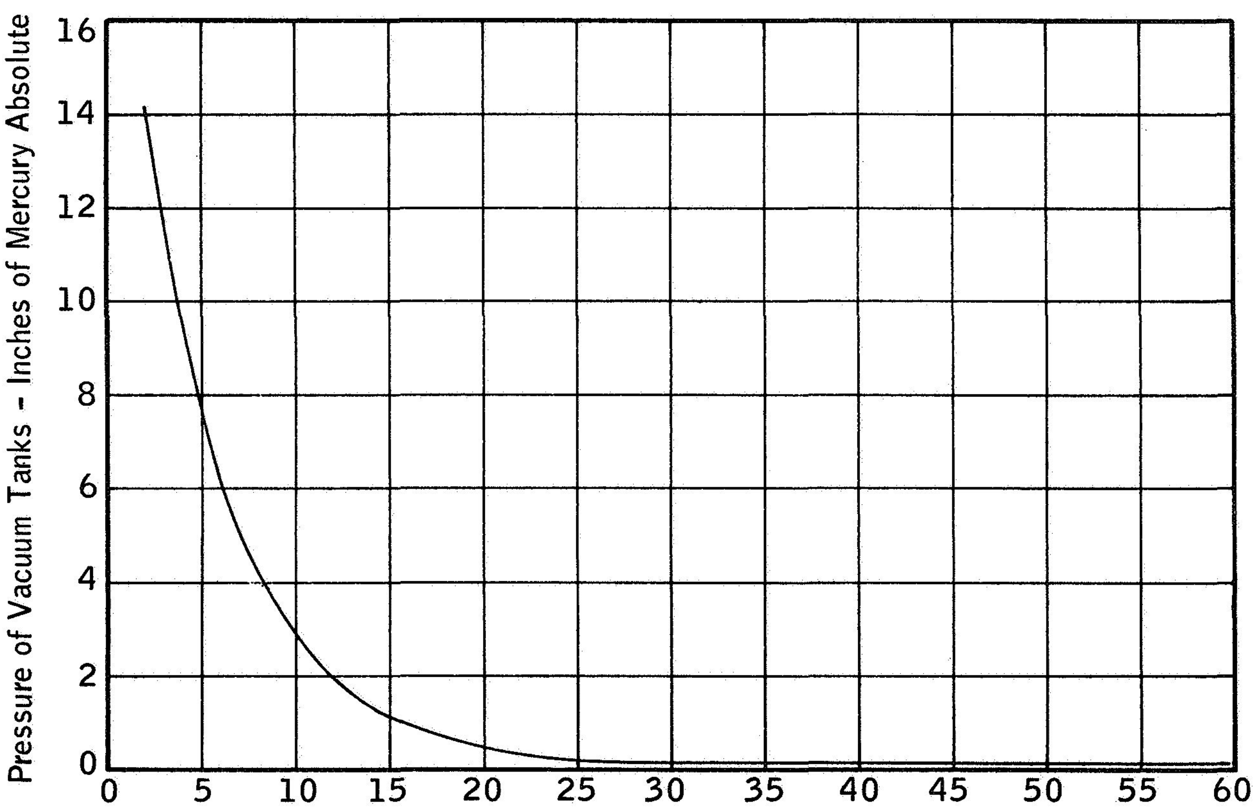


FIG. 6b. VACUUM PUMPING RATE

Operational Characteristics

The 14 x 14-Inch Trisonic Wind Tunnel is capable of performing a varied range of testing. The transonic section offers a useable testing range of 0.3 to 2.5 with the exclusive feature of a variable porosity test section. This distinction allows the wall porosity to be set so as to provide optimum wave cancellation for each Mach number. Plenum suction is provided by the auxiliary vacuum line with the tunnel normally exhausting to atmosphere.

The changeover from transonic to supersonic requires approximately 30 minutes and can usually be performed during pump-up or charging time. The supersonic section extends the Mach range from 2.75 through 5.00.

The operational range of stagnation pressures of 22 to 105 psia is a function of Mach number and tunnel limits. This pressure range results in a dynamic pressure range of 288 PSFA to 2880 PSFA. The corresponding Reynolds number range is one million to eighteen million per foot. The nominal average stagnation temperature is 100°F. These operational criteria are presented graphically in Figures 7, 8, and 9.

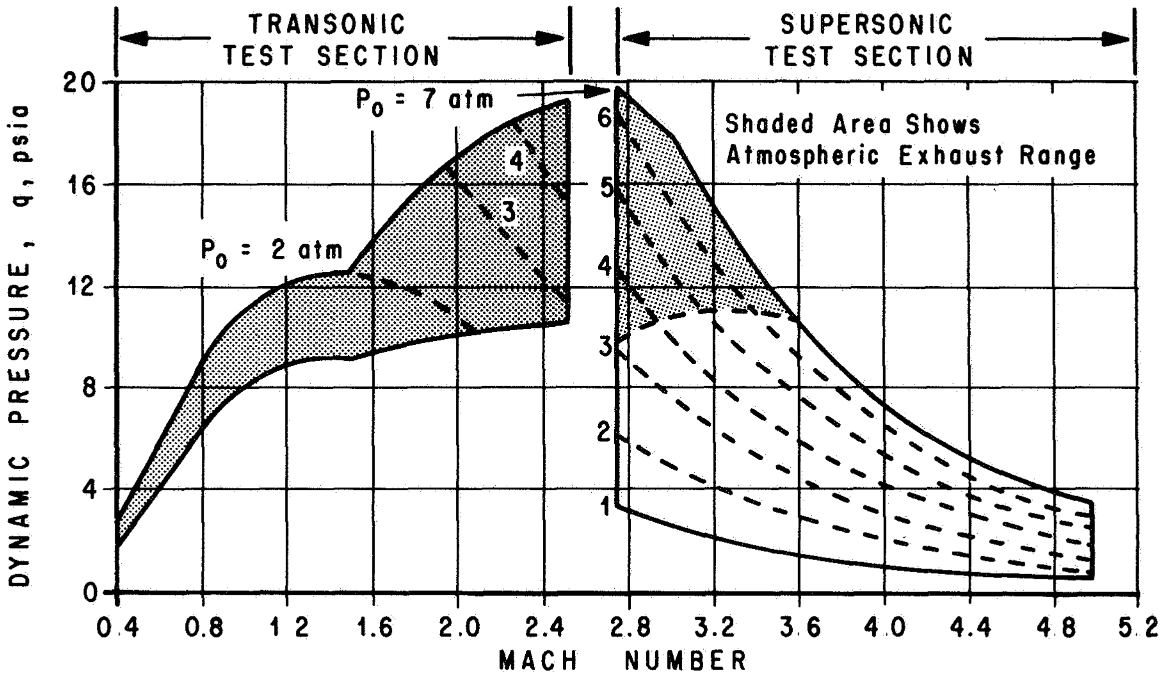
The maximum run times are approximately three minutes for the most favorable transonic condition, and about 40 seconds for supersonic flow with vacuum exhausting. Force tests require approximately eight seconds per angle of attack, and pressure tests require approximately fourteen seconds per angle of attack.

The run time is dependent upon the Mach number and tunnel operating conditions. This is shown graphically in Figure 9.

A tunnel calibration is not presented in this report, but is referenced to the wind tunnel calibration handbook [1]. The Handbook presents a complete centerline Mach number calibration, transonic cone-cylinder pressure distributions, and flow angularities. All deviations from the surveyed flow are within the normally accepted values.

MODELS AND MOUNTING

Introduction. In general, the two types of testing currently being done in the tunnel are static stability and pressure tests. Although the tunnel is not restricted to these types, other types of tests may require special planning and preparations. A special test section (Figure 4) using a plug nozzle concept is available to perform certain investigations of base flow phenomena such as those associated with multi-engine boosters. The "model" or vehicle base region is an extension of the nozzle plug. A 3500 psia air source is available to simulate engine flow.



14" X 14" TUNNEL DYNAMIC PRESSURE ENVELOPE

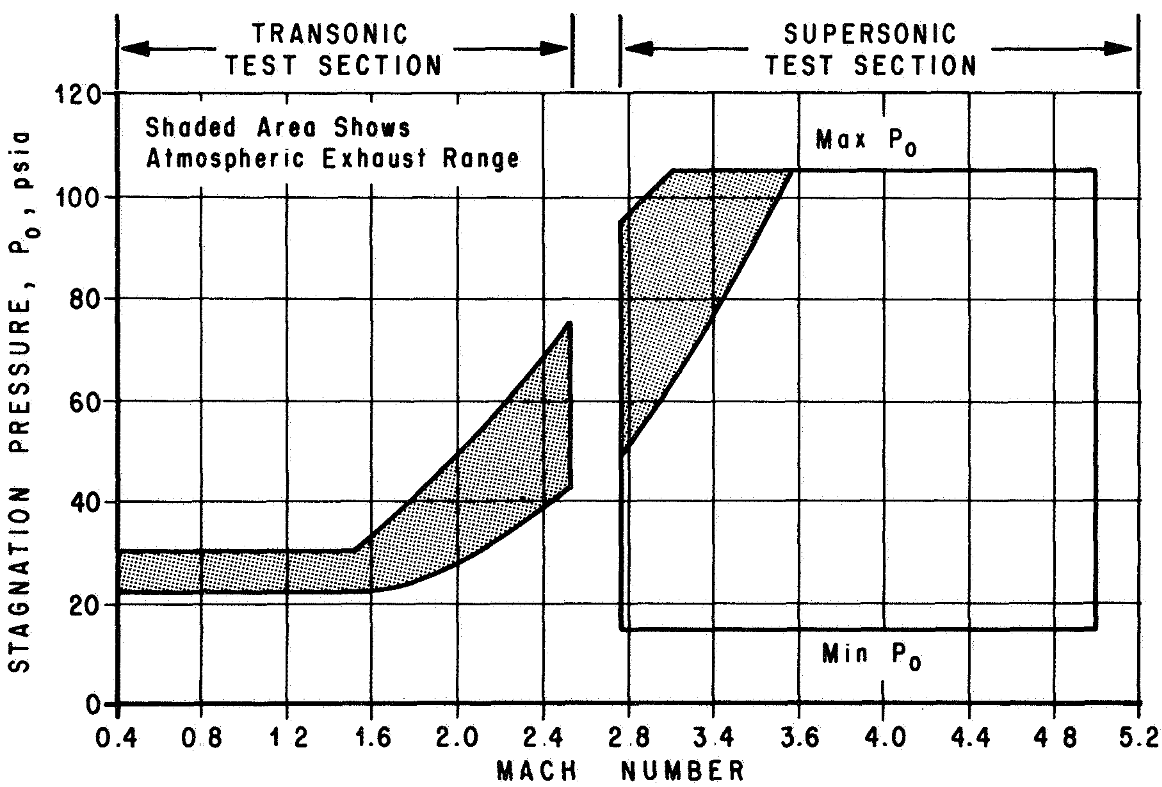
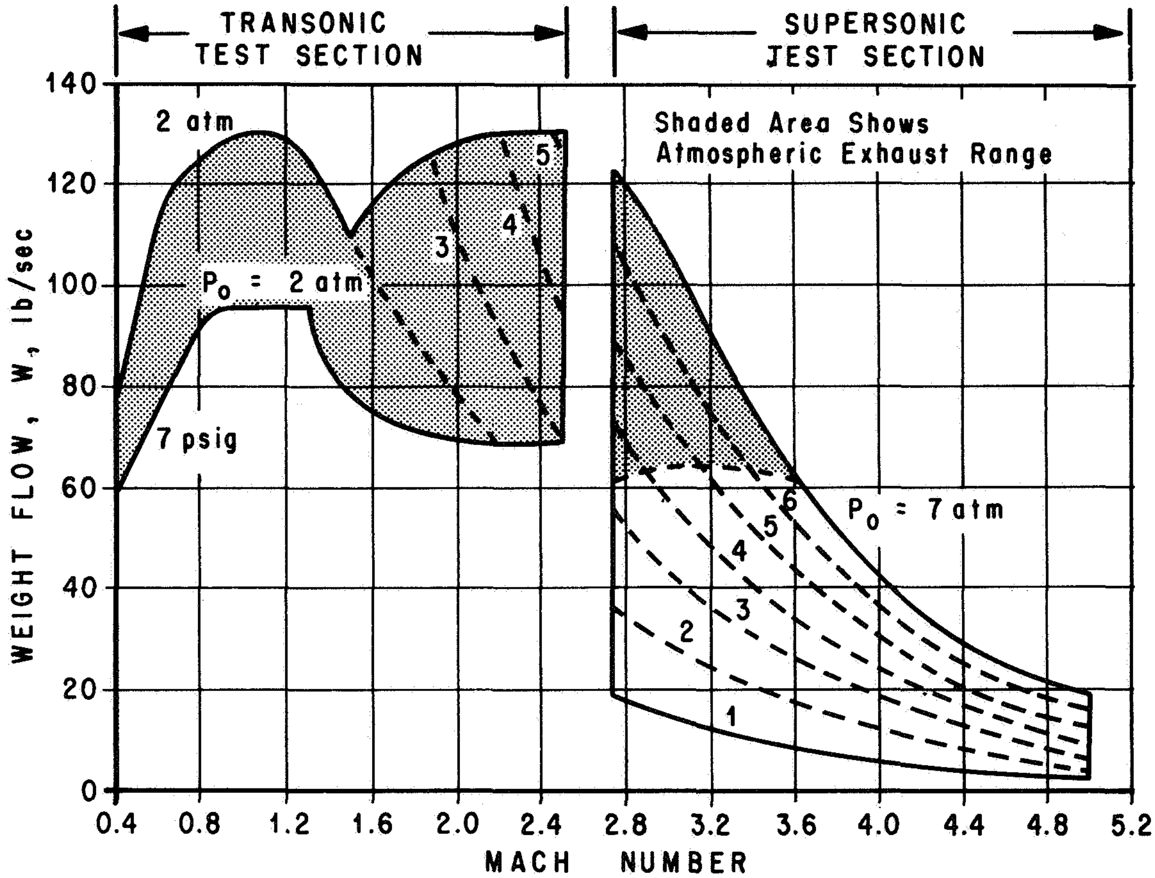
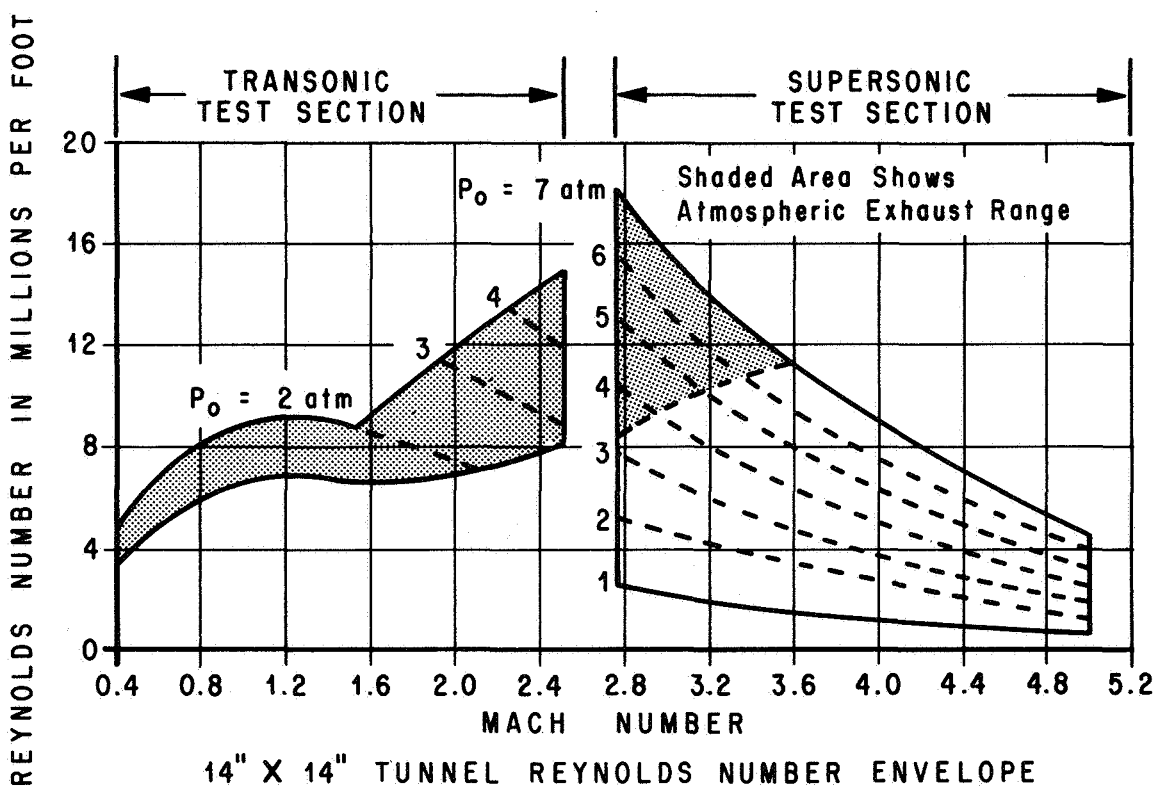


FIGURE 7. STAGNATION AND DYNAMIC PRESSURES



14" X 14" TUNNEL WEIGHT FLOW ENVELOPE



14" X 14" TUNNEL REYNOLDS NUMBER ENVELOPE

FIGURE 8. REYNOLDS NUMBER AND MASS FLOW VERSUS MACH NUMBER

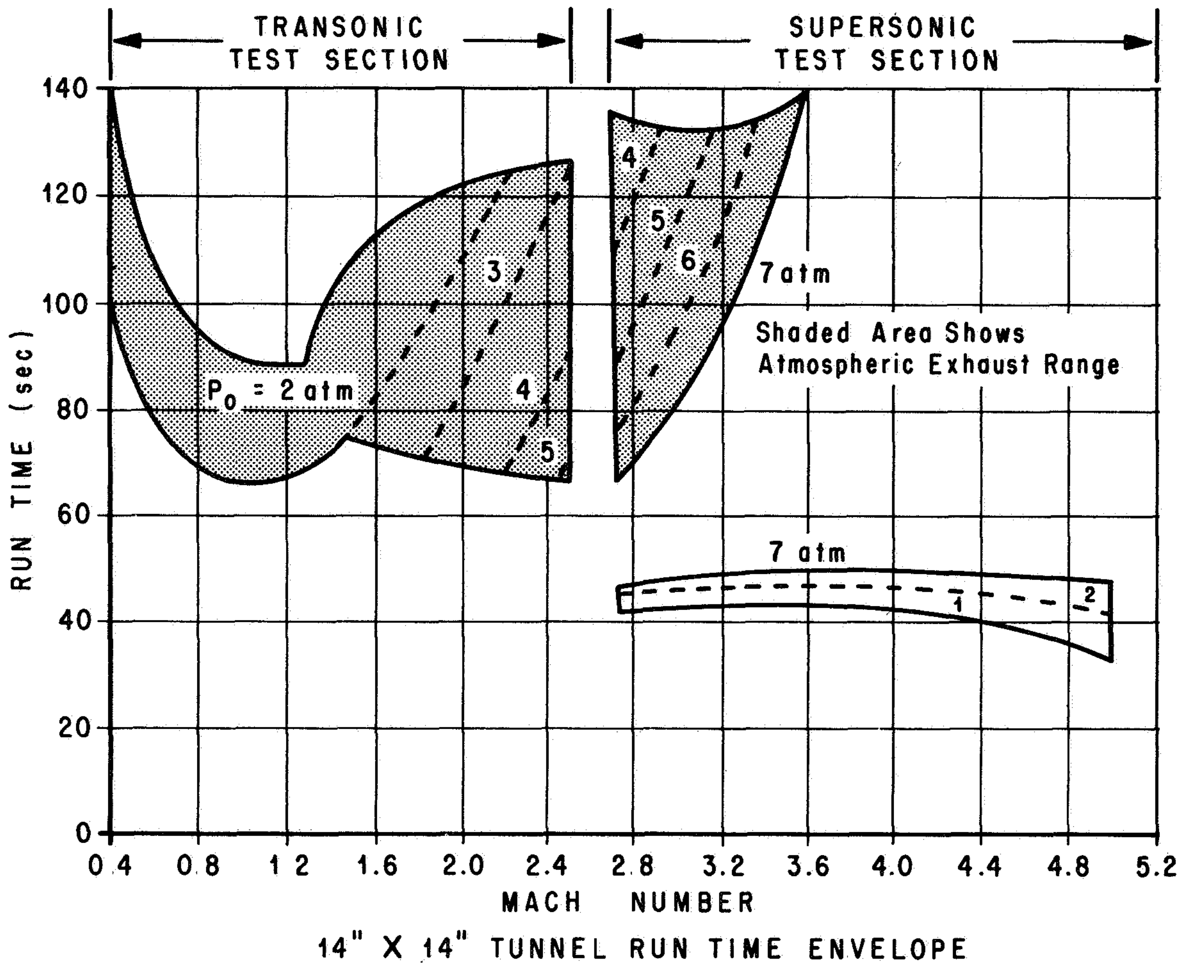


FIGURE 9. RUN TIMES VERSUS MACH NUMBER

All models must have adequate provisions for leveling when in the tunnel in the pitch and roll plane. This can be accomplished with "flats" or suitable pin locations.

Model Sizing. The maximum model size is largely dependent on the individual model geometry, Mach number, and Reynolds number. It is difficult to specify exact rules for model sizing. A general "rule of thumb" guide for model sizing is that launch vehicle configurations and similar bodies of revolution can be tested with reliable results if the model base diameter is three inches or less and the length is fourteen inches or less. The controlling criteria affect not only tunnel starting but also proper wake establishment. In unusual cases, it is recommended that the test originator discuss the specific configuration and test requirements with facility and design personnel before model design.

Starting Loads. It is inherent in an intermittent supersonic facility that, during the starting or stopping sequence, a high energy force is applied to the model due to the shock wave moving through the test section. This force is much greater than the normal running air loads. The "Normal Shock" theory is considered to provide the most acceptable approach to determine these loads. This theory assumes that a normal shock exists at the leading edge or nose of the model and is extended in one direction only. A plot of normal shock theory starting coefficient as a function of Mach number is presented in Figure 10. The

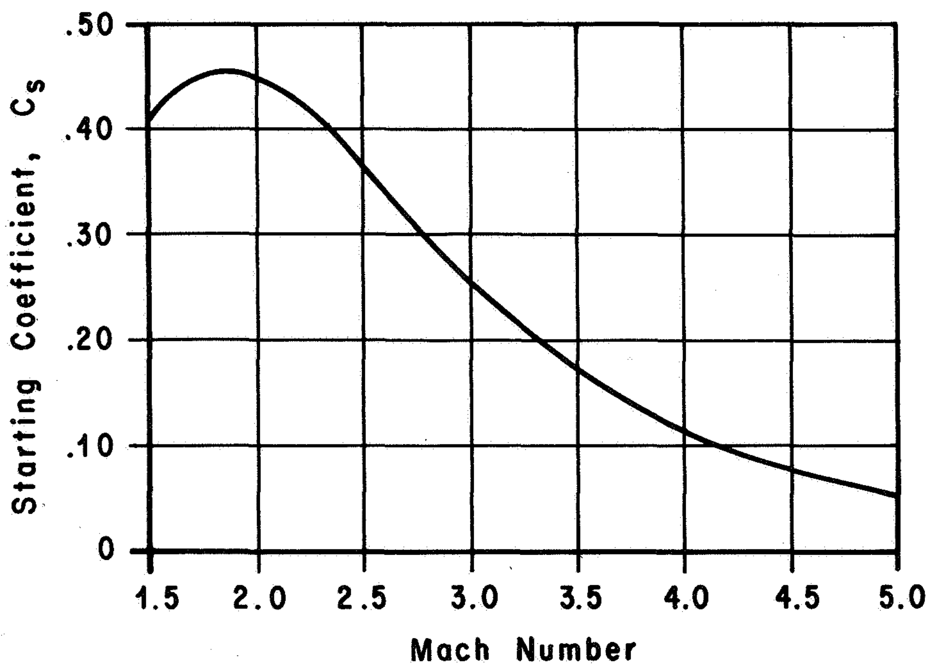


FIGURE 10. VARIATION OF NORMAL SHOCK THEORY STARTING COEFFICIENT, C_S, WITH MACH NUMBER

normal shock theory starting coefficient is defined as starting normal force divided by the stagnation pressure times the total projected area. On the basis of experiments conducted by AEDC, it is recommended that two-thirds the normal shock starting load be used for all bodies of revolution with small fins or vanes [2].

Starting and stopping model loads have been minimized by two systems. Throughout the testing range a quick-acting dump valve located in the settling chamber is used. This valve opens at "shut-down" to release the remaining air in the settling chamber, thus reducing the tunnel stopping process, and minimizing stopping loads. The model starting loads in the supersonic range have been minimized by evacuating the test section immediately before starting the tunnel. The starting shock therefore moves through the test section much faster than when the tunnel is started with the test section at atmospheric pressure.

Pressure Models. A set of ten pressure multiplexers (scanivalves) are capable of measuring up to 240 pressures. The scanivalves are driven by stepping solenoids in sets of five. The scanivalves are located as close to the model as feasible to minimize the pneumatic response of the system. Typically tubing length is 3 - 5 feet.

Pressure tubes from the models are connected at the tunnel walls through a quick disconnect bulkhead fitting.

Plastic tubing is used to connect the model tubing to the quick-disconnect blocks. All pressure orifices on the model should be flush and perpendicular to the external surface and should not be less than 0.040 inches in diameter. Model tubulations should be .049 O.D. stainless steel for system compatibility.

The model is tubed up to the mating terminal plugs before the test, thoroughly flushed with solvent, and then leak-checked. This advance "setup" substantially reduces the installation time.

Static Stability Models. Static stability models are normally mounted on a NASA-furnished balance and sting except for certain unusual cases. The appropriate sting-balance combination will normally be chosen by the model design staff from criteria furnished by the originating aerodynamics group. Certain considerations such as those presented below are generally the selection points:

1. Ranges of forces and moments

2. Space limitations of the model balance cavity

3. Proper tunnel placement

4. Correct balance-model placement so as to locate the model center of pressure as close to balance center as possible.

Any additional information on balances and sleeves available may be obtained from the Gas Dynamics Sections, Experimental Aerophysics Branch, Aerophysics Division, Aero-Astrodynamics Laboratory.

If base pressure corrections are to be applied to axial force data, provisions must be made to have a transducer line leading to the model base or cavity area. These pressures are measured by individual transducers mounted externally to the air stream about three feet from the model.

Model Mounting Hardware. A family of compatible model stings, sting offsets, sting extensions and special purpose stings are available for test installations at the 14 x 14-Inch Trisonic Wind Tunnel. The center of rotation at tunnel station 20 determines the proper model placement, and once the length from the center of the model to the end of its sting is known, the associated mounting hardware can be determined.

For an angle-of-attack range ±10°, a straight sting extension is picked from those listed in Figure 12. For pressure tests, a pressure sting extension may be chosen from those listed in Figure 13.

Both the sting extensions and offsets can be adapted with the use of collet-type inserts to chuck four sting diameters: 0.500, 0.625, 0.750 and 0.875 inches.

If a higher angle of attack is desired, there are several offsets available for 6°, 8°, and 15°, furnishing up to 25° angle of attack. The offsets are available for various model sting lengths. The offsets are shown in Figures 14 and 15. The 6° and 15° offset incorporated in Figure 14 will provide an angle of attack of -4° to +25° in two runs. This arrangement allows the relative model-tunnel dimensions to remain constant in switching between the two ranges.

A special knuckle sting (Figure 11) is available that can provide an angle of attack range of -10 to +40 degrees or a similar yaw range when rolled 90 degrees. Due to the length of the sting special attention should be given to model base location.

A wide assortment of "special test" stings is available but must be considered on an individual basis. If the listed stings do not meet the test requirements, then contact the chief of the Gas Dynamics Section, Experimental Aerophysics Branch, Aerophysics Division, Aero-Astrodynamics Laboratory.

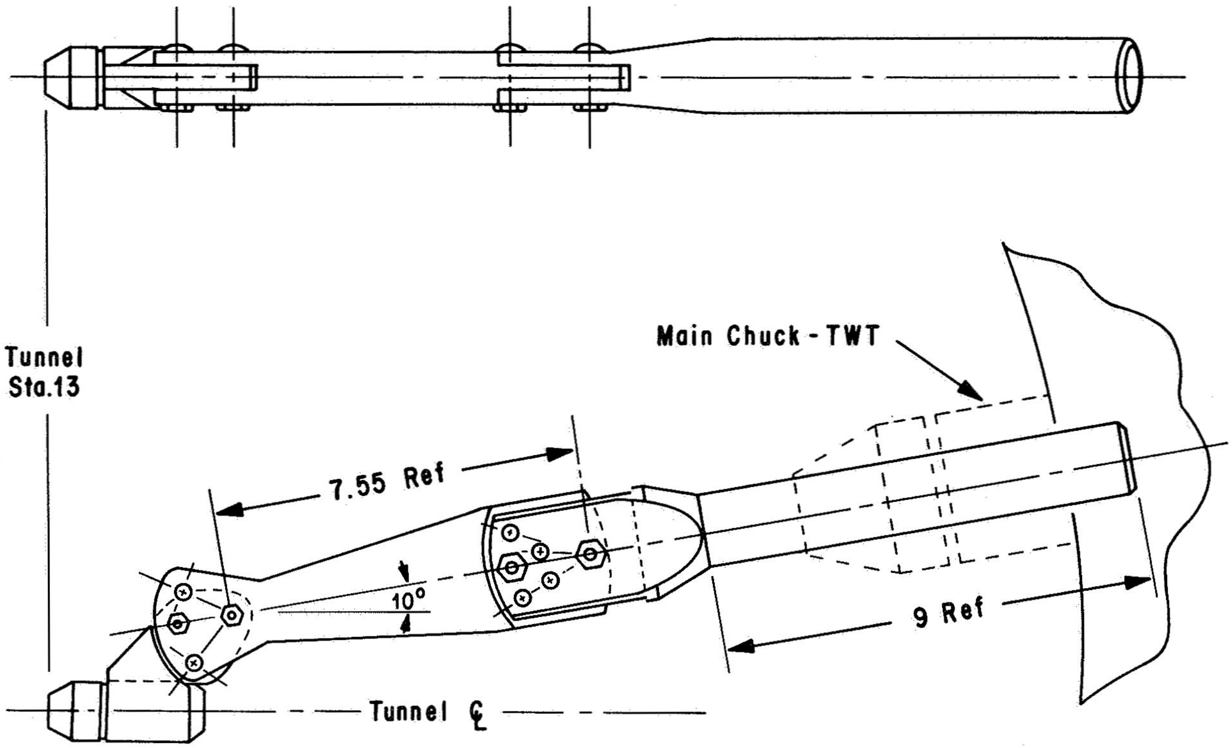
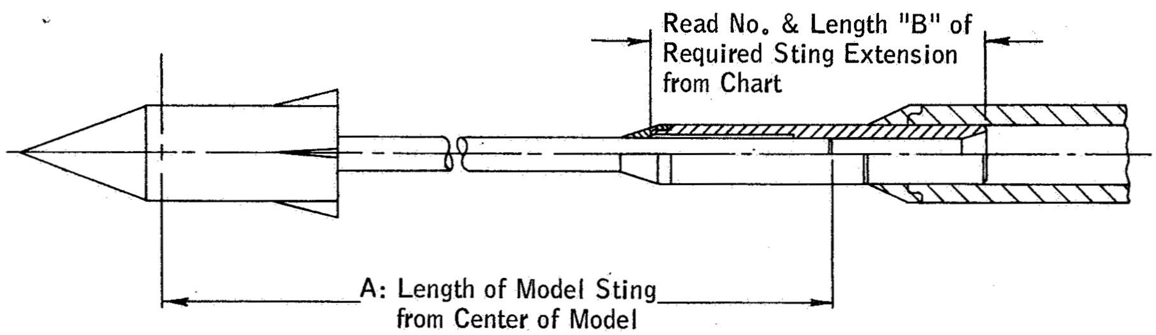


FIGURE 11. KNUCKLE STING



A	Sting Ext. No.	B	A	Sting. Ext. No.	B
7 - 8	S 7	20.5	15 - 16	S 4	14.5
8 - 9	S 7	20.5	16 - 17	S 3	12.5
9 - 10	S 7	20.5	17 - 18	S 3	12.5
10 - 11	S 6	18.5	18 - 19	S 2	10.5
11 - 12	S 6	18.5	19 - 20	S 2	10.5
12 - 13	S 5	16.5	20 - 21	S 1	8.5
13 - 14	S 5	16.5	21 - 22	S 1	8.5
14 - 15	S 4	14.5	22 - 23		

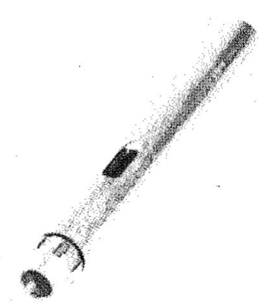
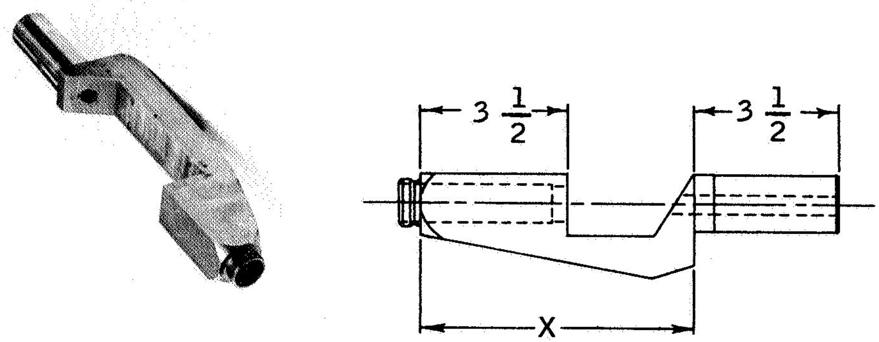


FIGURE 12. STRAIGHT STING EXTENSIONS



Sting Ext. No.	X Inches
S 2	6.5
S 3	8.5
S 4	10.5

FIGURE 13. PRESSURE STING EXTENSION

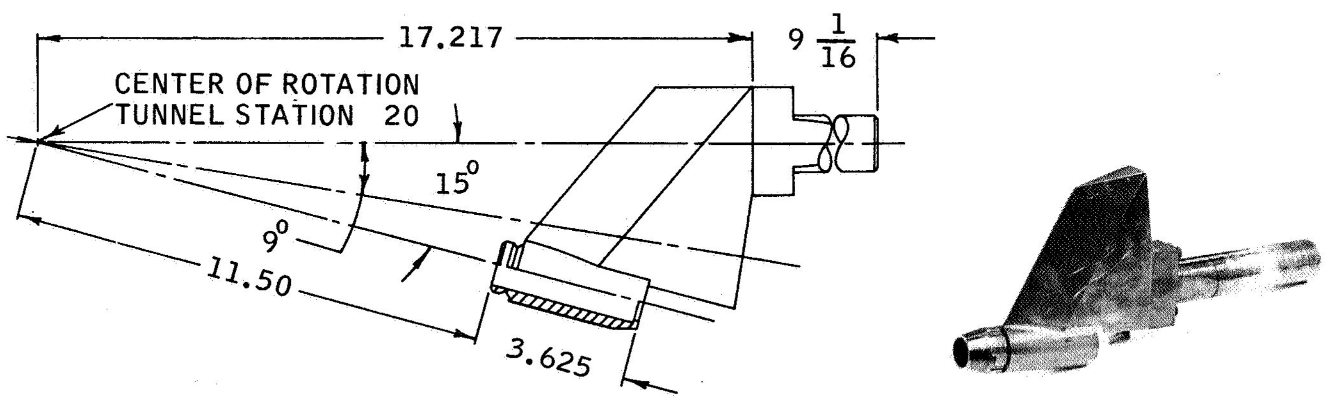
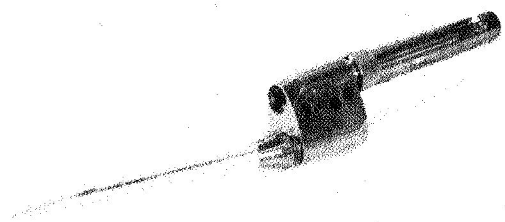
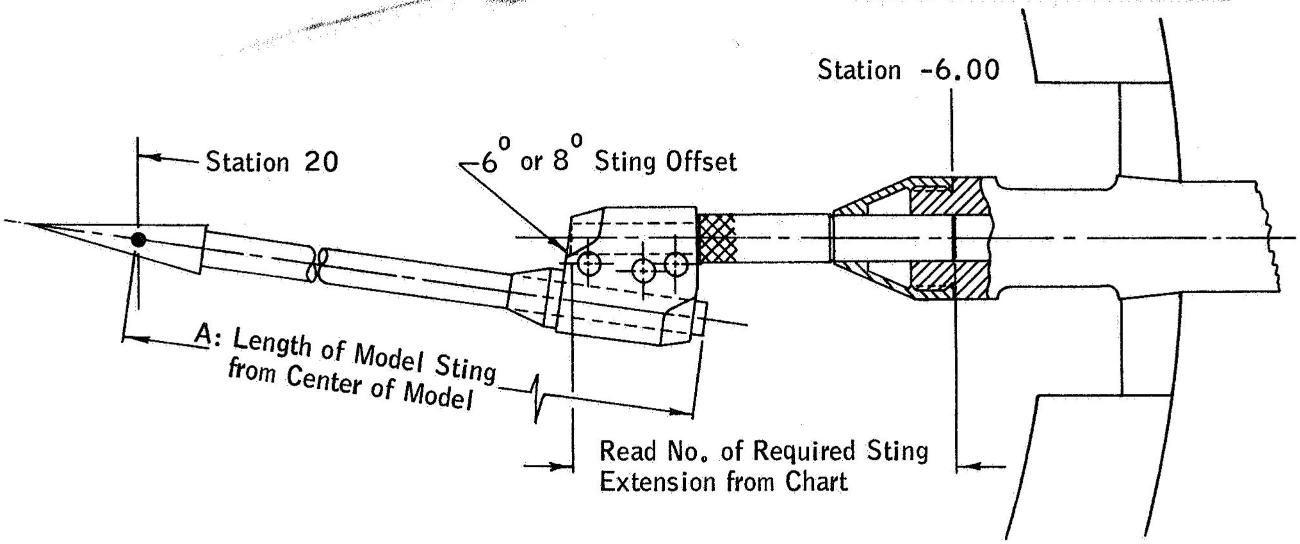


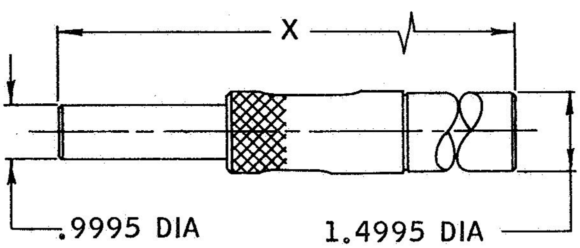
FIGURE 14. OFFSET, 6° AND 15° INCORPORATED

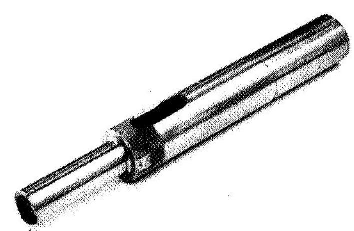


If Length "A" is:	Use Offset No.	Use Ext. No.
14.5 - 16.5	12	04
16.5 - 18.5	14	03
18.5 - 20.5	16	02



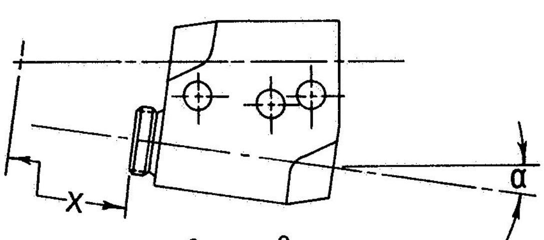
Ext. No.	X Inches
01	7.5
02	9.5
03	11.5
04	13.5

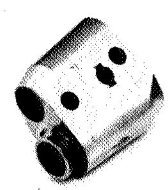




Sting Extension

X Inches	α Deg.	Offset No.
10	8	10
12	8	12
14	8	14
16	8	16
12	6	12 - 6
14	6	14 - 6
16	6	16 - 6





6° and 8° Offsets

FIGURE 15. SCHEDULE OF STINGS FOR THE 6° AND 8° OFFSETS

Model Support System. The model is positioned in the "pitch" plane by a remotely controlled hydraulic sector drive as shown in Figure 16. The sector carries a center sting with a chucking device for supporting the miscellaneous model stings as previously mentioned. The sector has a fixed center of rotation at tunnel station 20. The tunnel may be opened at the test section diffuser junction for access to the sector and model hardware. A quick disconnecting pressure plug is located at the intersection of the sector and the center sting.

Three model positioning modes are set up in the control system: manual, pitch-pause, and velocity. The pitch-pause mode allows the model to assume a preselected series of angular positions, pausing at each angle to allow data sampling before proceeding to the next position. Up to 19 angles may be taken in this mode. The manual mode allows angular positions to be manually set by a potentiometer mounted on the control console. The manual mode is used during calibrations and special tests. The velocity mode allows the model to move at a constant rate between two chosen angular positions with the velocity adjustable up to about 20° per second. In all three modes, the model may be pitched in a vertical plane through a 20° angle-of-attack range.

INSTRUMENTATION AND DATA HANDLING EQUIPMENT

Static Stability Instrumentation. All model force and moment data are measured by internal strain gage balances. A wide variety of sizes and load ranges are available for model installation. Balances are periodically calibrated and then check calibrated before each test. Calibration constants are determined from prime loadings of the balance. Combined loadings are taken for further balance evaluation. Weight tares are taken for all models, and corrections applied to the final data.

Check loads are hung on the model when installed in the tunnel, which serves to set balance sensitivities and check transfer distances. This procedure is repeated periodically during each test and at the conclusion of the test.

Deflection of the model sting and balance due to aerodynamic loads is taken into account and the angle of attack corrected where deflection becomes excessive.

The most commonly used balance is the six-component type that measures normal force, side force, pitching moment, yawing moment, rolling moment, and axial force. A typical balance is shown in Figure 17. Rated balance loads vary from 1.6 to 150 pounds normal force, with the moment capabilities consistent with the normal force loads and

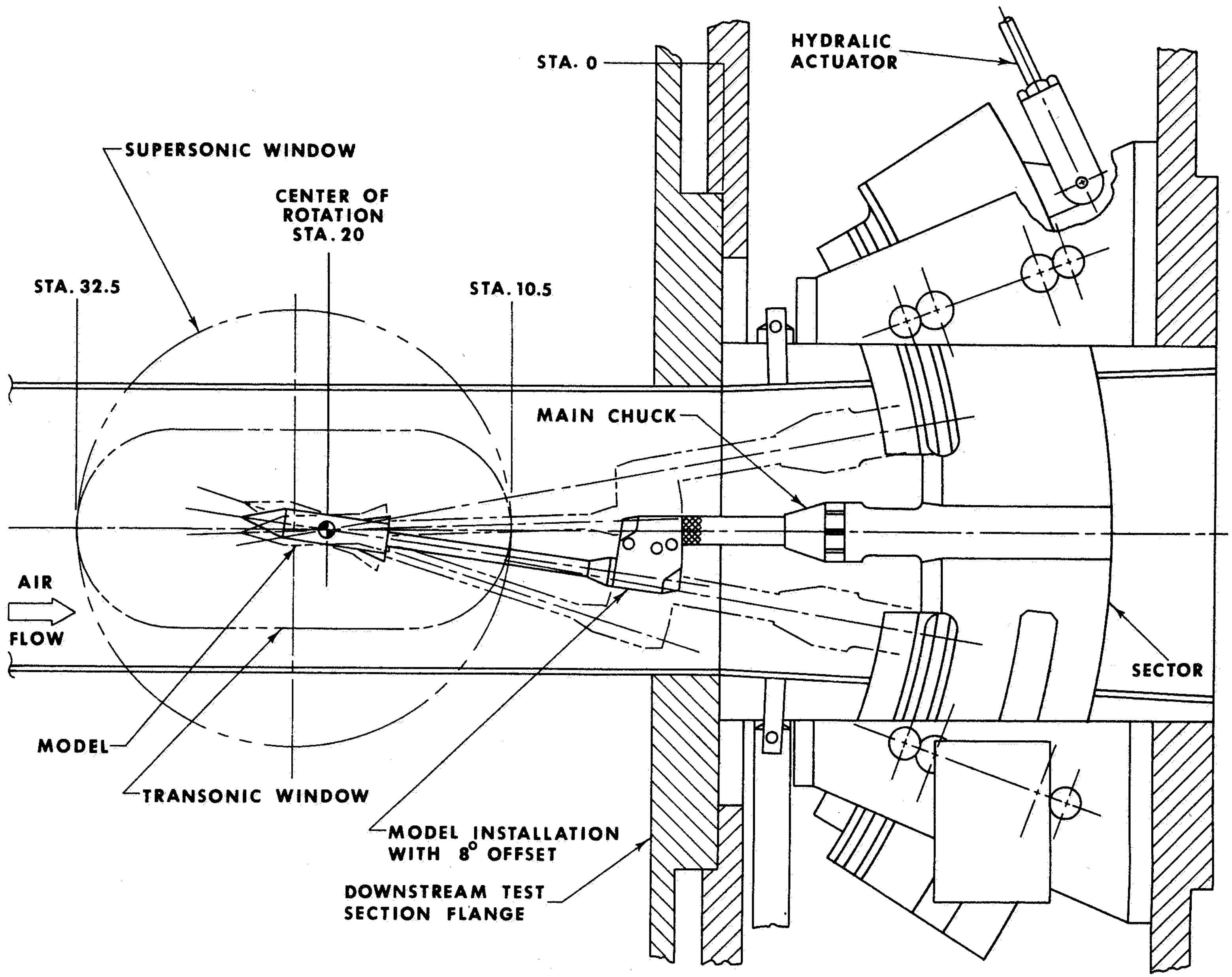
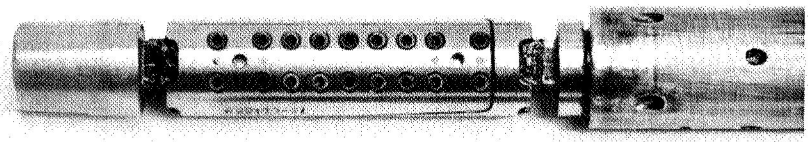


FIGURE 16. MODEL SUPPORT SYSTEM GEOMETRY



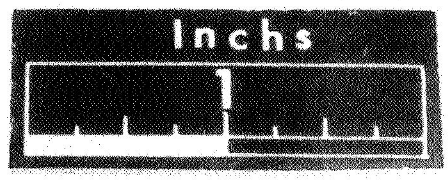


FIGURE 17. TYPICAL THREE-COMPONENT MODEL BALANCE

expected centers of pressure. The table in Figure 18 gives the available balances for the 14 x 14-Inch Trisonic Wind Tunnel [3]. Presented are the balance number, the type balance, the load range and the important dimensions.

Balances furnished by outside users may be used if they are compatible with existing mechanical hardware and data system.

Pressure Instrumentation. The two pressure measuring systems currently employed at the 14 x 14-Inch Trisonic Wind Tunnel are pressure scanning switches and single transducers. Standard half-inch, flush diaphragm, strain gage transducers are used for both systems. Transducers ranging from 5 psid to 500 psia are available to the user. For normal running, 5 psia 12 1/2 psid, and 25 psid transducers are used.

The pressure measuring system consists of two solenoid-driven banks of five 24 port pressure multiplexers (scanivalves) capable of measuring up to 240 pressures. A single scanivalve bank is shown in Figure 19. A schematic is shown in Figure 20.

Pressure tubing connecting the model to the measuring system ranges from four to five feet in length. Due to the "Pitch Pause" sampling technique, pneumatic line lag is negligible.

Balance Number	Balance Components	BALANCE CAPABILITIES (1)					Balance Diameter (inches)	Balance Length (inches)	REMARKS
		Normal Force (lbs)	Pitching Moment Fwd./Aft (in-lbs)	Side Force (lbs)	Rolling Moment (in-lbs)	Axial Force (lbs)			
176	3	37	50/50	-	-	30	.625	4.387	
177	3	40	35/59	-	-	30	.625	4.387	
180	3	44	35/75	-	-	30	.625	4.387	
182	3	46	60/60	-	-	13	.500	4.187	
184	3	44	35/75	-	-	56	.625	4.387	
185	3	76	96/96	-	-	30	.625	4.387	
190	3	288	360/360	-	-	60	.70	6.813	
191	3	135	168/168	-	-	14	.625	4.387	
192	2	3	4/4	-	-	-	.284	4.772	Special
200	6	175	185/185	150	50	100	.750	6.125	(2)
201	6	60	60/60	20	25	30	.50	4.000	(2)
209	3	45	45/45	-	-	35	.50	3.875	(2)
210	3	45	45/45	-	-	8	.50	4.775	(2)
222	3	60	60/60	-	-	30	.50	3.875	(2)
225	3	100	100/100	-	-	60	.50	3.875	(2)
226	6	80/160	90/180	50	40	30	.625	4.798	(2)
227	6	150	175/175	60	45	25	.625	4.798	(2)
231	6	75	75/75	30	30	20	.50	4.000	(2)

(1) These are nominal values.

(2) Balances have a forward and aft taper of 1 in/ft and are generally interchangeable for the same diameters.

FIGURE 18. BALANCE LISTING

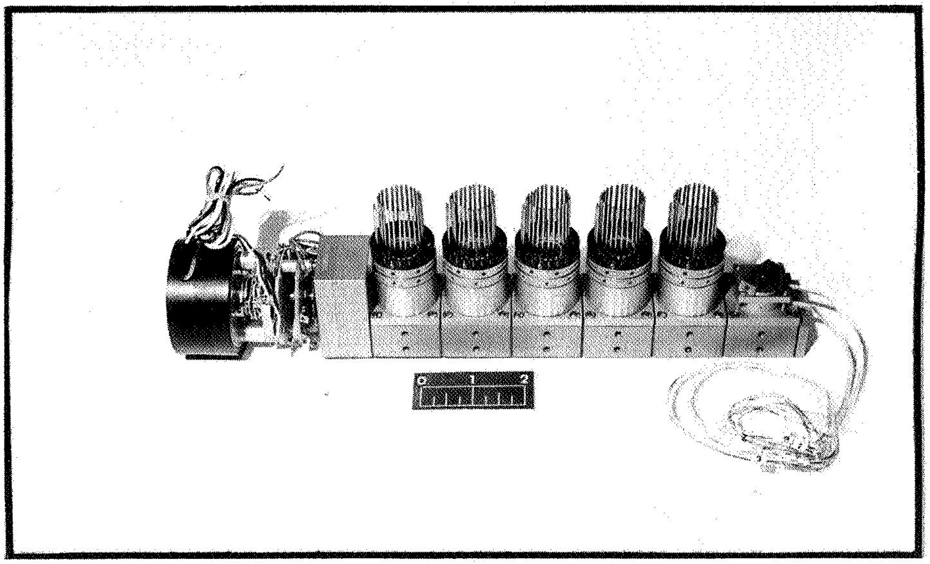


FIGURE 19. PRESSURE SWITCHES (SCANIVALVES)

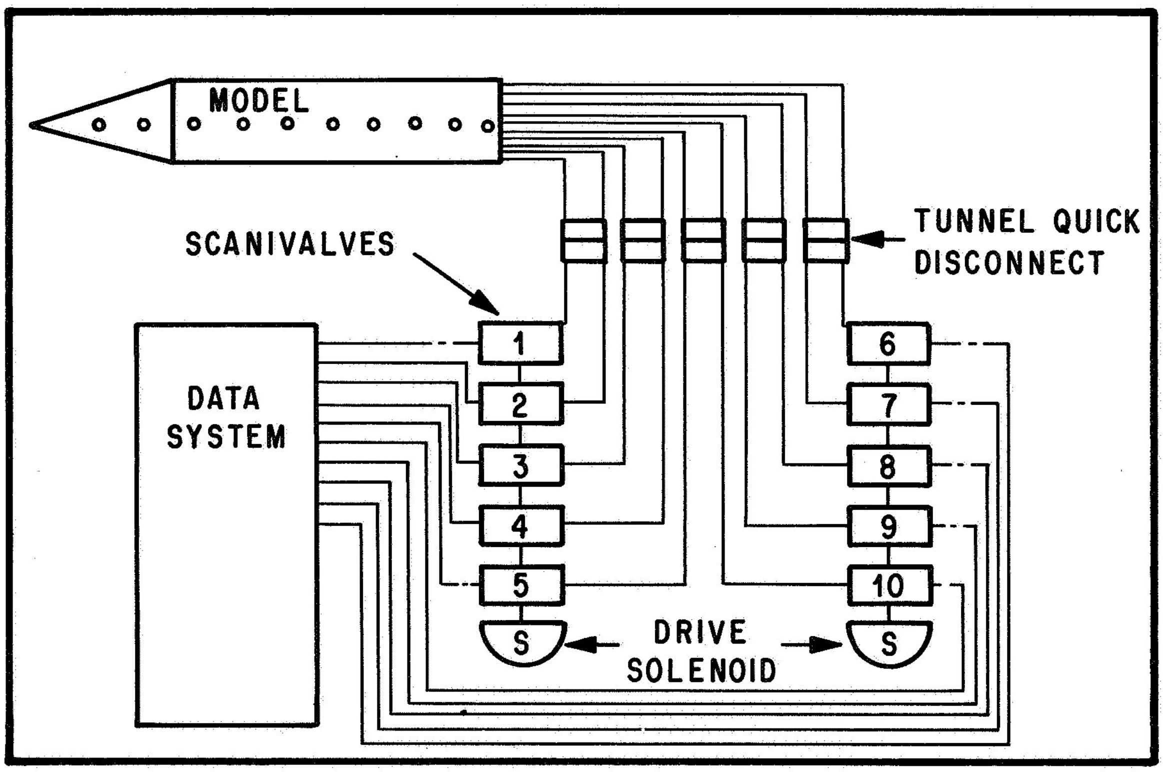


FIGURE 20. SCANIVALVE MODULE

Up to ten pressures may be measured by using single transducers mounted externally.

Data are sampled and punched out in digital form on cards during the run. All transducers are checked at least once every eight hours of testing or more often, as needed. Bench calibrations are periodically conducted on all active transducers.

Miscellaneous Instrumentation. Instrumentation for other than routine tests is available on advance notice. Temperature and acoustic pickups are available, and have been used in the special test section.

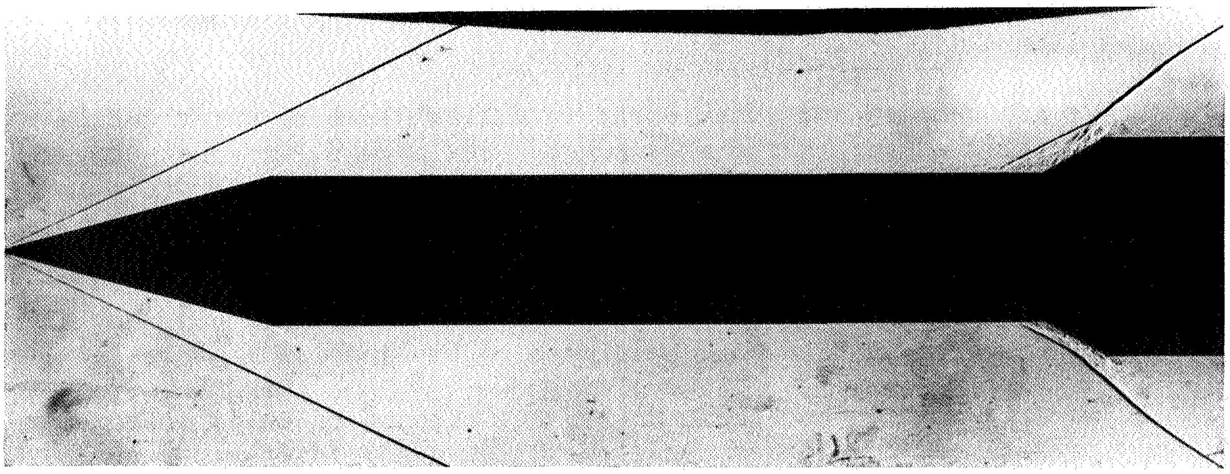
Dynamic tests can be accommodated, but because of their infrequency, additional lead times should be allowed for instrumentation preparation.

Flow Visualization. Flow visualization can be obtained by several different methods. The direct shadow, or shadowgraph [2] method is generally the most popular means of observation. The shadowgraph is recorded on 10" x 20" high speed black and white film. The model image is recorded on the film at approximately 1.5X magnification and can be varied by moving the spark source toward (higher magnification) or away from (lower magnification) the model. The shadowgraph image is roughly proportioned to the second derivative of the flow density, thus simplifying interpretation. The shadowgraph is used extensively in boundary layer studies. Film handling limits the rate to only two or three shadowgraphs during a run (30-second cycle time). A roll film adapter is available requiring only a three-second cycle, but is not generally used because of inherent disadvantages [4].

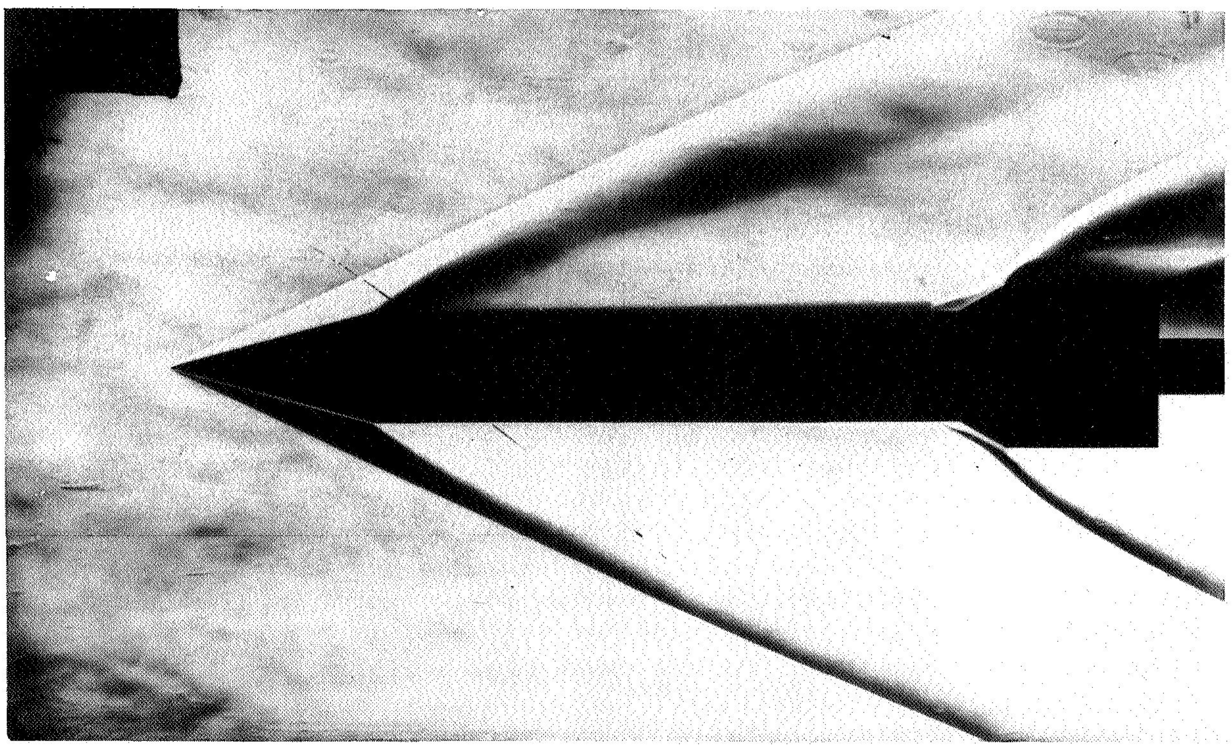
The Schlieren system [5] differs from the shadow method in that the Schlieren image is proportional to the first derivative of the density. A direct comparison can be made from the photographs in Figure 21. The image from the Schlieren is recorded on either still film or motion picture film. The Varitron and Polaroid still cameras share the same lens system. The Varitron camera records images on 70 mm film and produces up to 300 permanent negatives per roll of film. The polaroid film is for exposure checks and "on the spot" flow analysis.

Motion pictures are recorded on one of three cameras. The Fastax is a high speed 16 mm camera capable of up to 8000 frames per second on a 400-foot roll of film. The Milliken camera is a medium speed camera with a speed range of one to 400 frames per second on a 200-foot film roll. A Kodak Cine II is also available with film speeds of 16 fps to 128 fps on 100-foot film rolls.

Flow studies using oil and paint pigment have had some success in certain areas. An oil flow study is shown in Figure 22.



SHADOWGRAPH



SCHLIEREN

FIGURE 21. COMPARISON OF SCHLIEREN AND SHADOWGRAPH PHOTOGRAPHS AT MACH 2.44, $RN/L_C \approx 10^7$

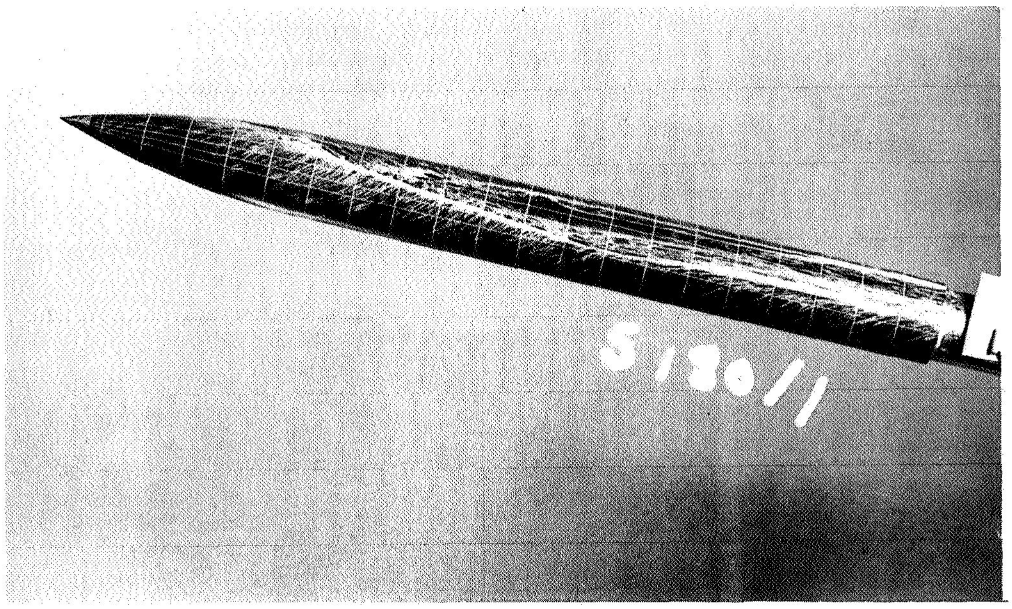


FIGURE 22. OIL FLOW STUDY

Calibration Equipment. The two categories of prime interest are balance-sting and pressure transducer calibration. Balances are furnished ready for tunnel installation. Original calibrations have been made using dead-weight loadings, precision calibration bodies, and precise alignment and loading techniques. After the balance is checked, the proper sting-balance is loaded and sting deflections recorded by the precision-mechanical measuring equipment (Figure 23). Dimensional model checks and measurement of model moment transfer distance are also made.

The balance is dead-weight loaded and checked through the tunnel data system and proper load sensitivities set up before running.

Pressure transducers are periodically checked by precise standards, and continuous checks are made daily in the tunnel by a precision dial manometer with a 45-inch sweep and a gage accuracy of 0.1 percent of full scale. Tunnel stagnation and static pressure pickups are also checked daily by similar means. The pressure calibration panel is shown in Figure 24.

FIGURE 23. PRECISION MECHANICAL MEASURING EQUIPMENT

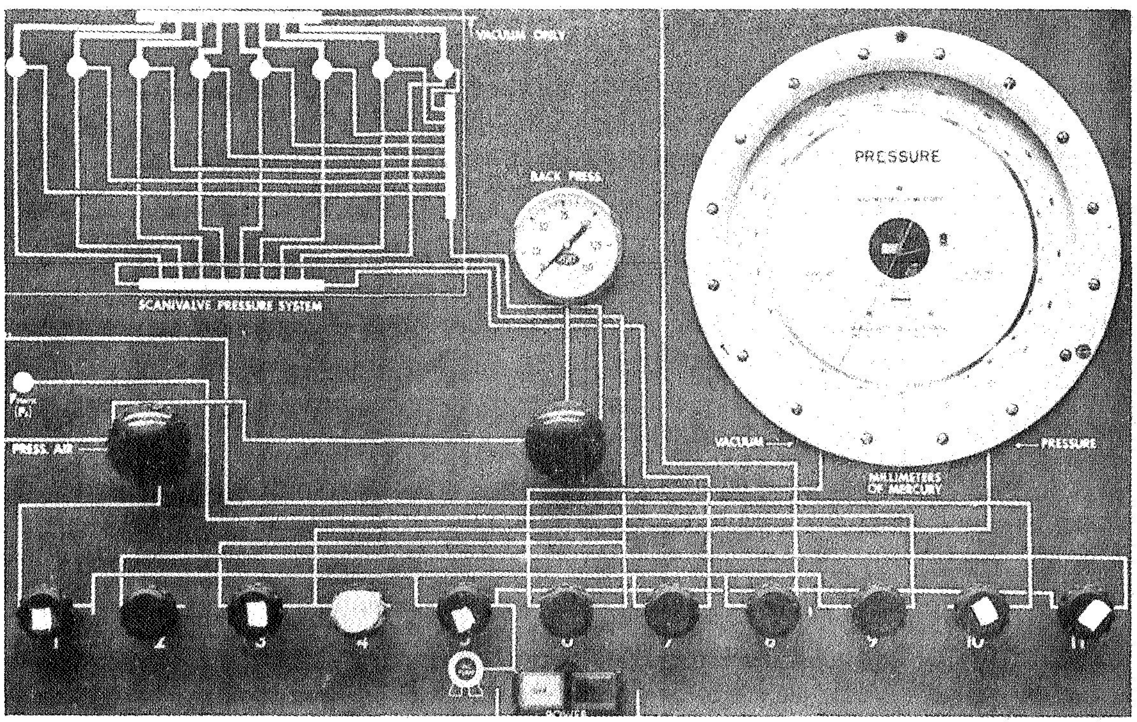


FIGURE 24. PRESSURE CALIBRATION PANEL

Data Recording Equipment [6]. Data acquisition equipment consists of a solid state digital acquisition system supplied by Systems Engineering Laboratories (SEL) and a programmer (see Figure 25).

The SEL equipment multiplexes 12 channels of low level signals, digitizes the multiplexed signal and punches the data using an IBM Summary Punch. Only 10 channels of the data system are used for experimental model measurements; the remaining two channels are used for tunnel parameters. There are four visual displays on the SEL unit that can monitor selected channels. Two visual displays on the control console provide stagnation and static pressure readouts. The six displays provide a four-place decimal readout with a full scale readout of ± 3999 counts.

The programmer functions as a control unit to synchronize the operations of the SEL data system and the IBM 523 Summary and Punch with the Scanivalve system, the angle-of-attack sector drive controller and the angle-of-attack encoder.

Time requirements for data acquisition differ from pressure and force testing. The normal pressure test requires approximately 10-12 seconds between angles of attack, with force testing requiring 3-4 seconds between angles of attack. These values are nominal and will change with test conditions.

Available immediately to the user is a printout typewriter for "quick checks" on the unscaled data. An automatic plotter may be used to check for linearity and repeatability of the data. A data system block diagram is presented in Figure 26.

DATA PROCESSING AND PRESENTATION

Data Processing. Data in the form of digital punched cards are furnished to the on-site computer. The computer, shown in Figure 27, is a General Electric 205 with an on-line printer system. Several programs are available for data reduction, including force and pressure programs. The force program covers both three and six component model balances. The pressure programs are extensive and include a local normal force program. Any program requirements not currently covered may be negotiated during initial test planning.

The calculated aerodynamic coefficients are punched on standard 80-column cards and printed simultaneously in tabular form by the line printer. The cards are then used by the automatic plotter (shown in Figure 28) to furnish final plotted data if requested by the project engineer. The plotting rate of the automatic plotter is about 100 points per minute.

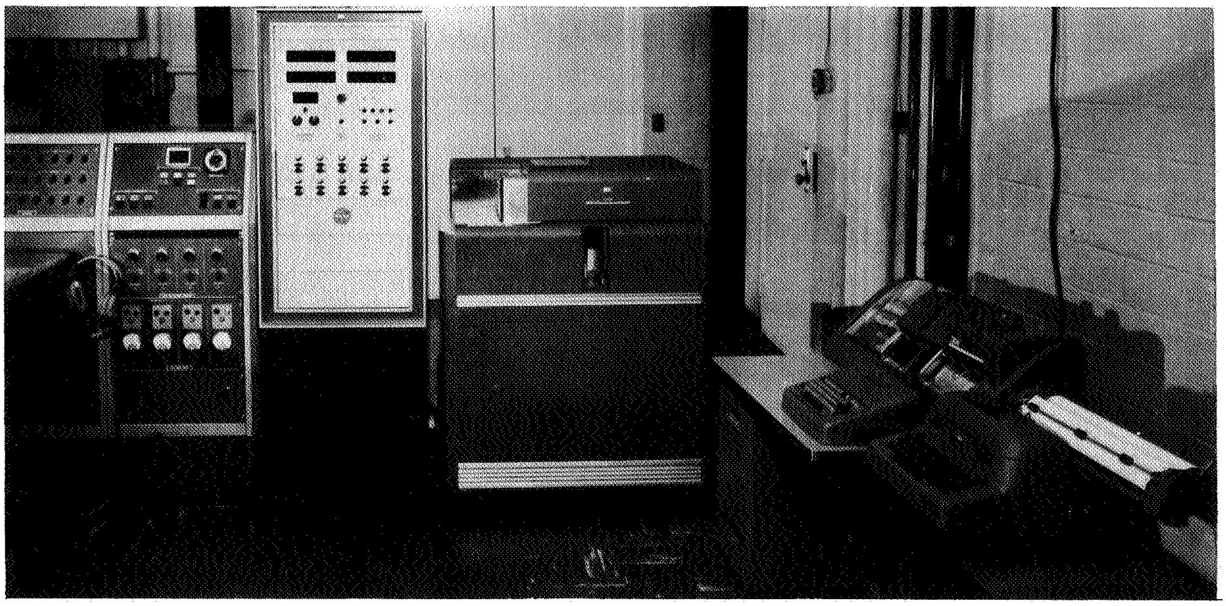


FIGURE 25. DATA ACQUISITION SYSTEM

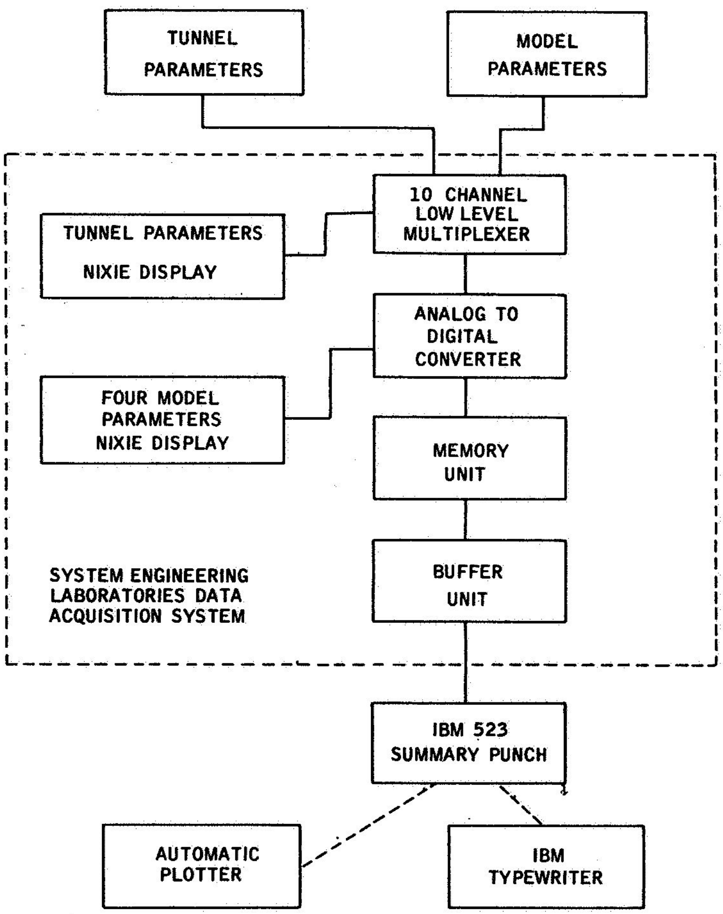


FIGURE 26. BLOCK DIAGRAM OF DATA ACQUISITION SYSTEM

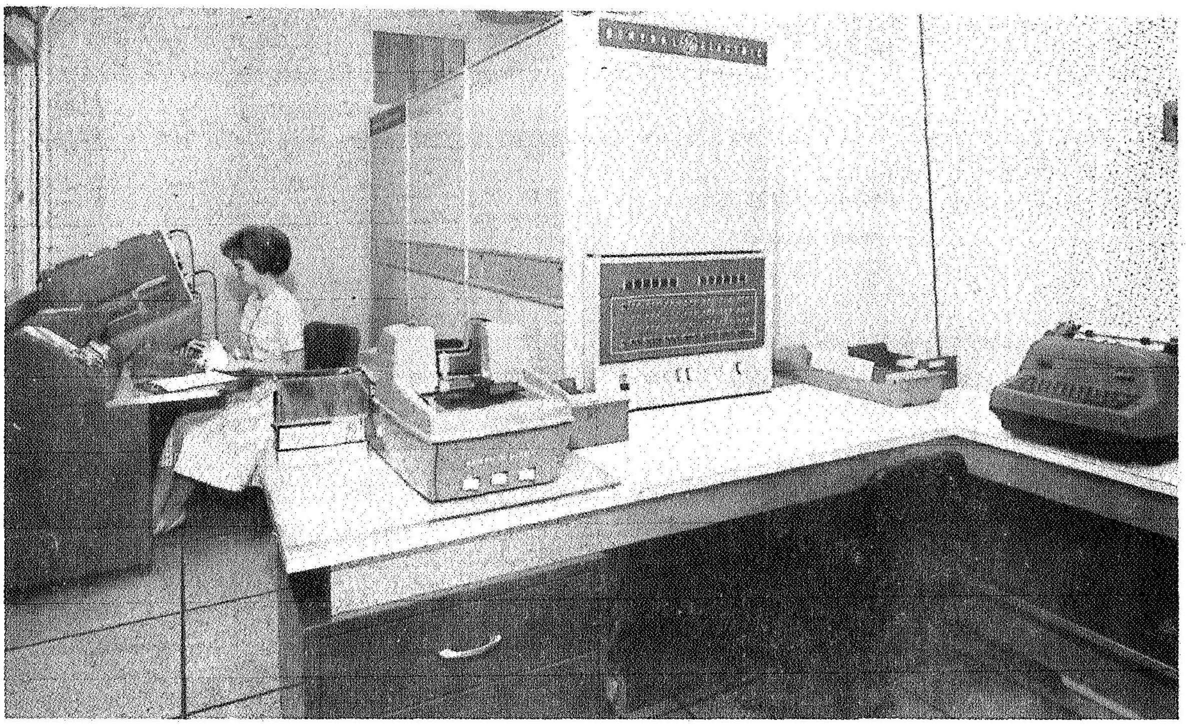


FIGURE 27. TUNNEL COMPUTER

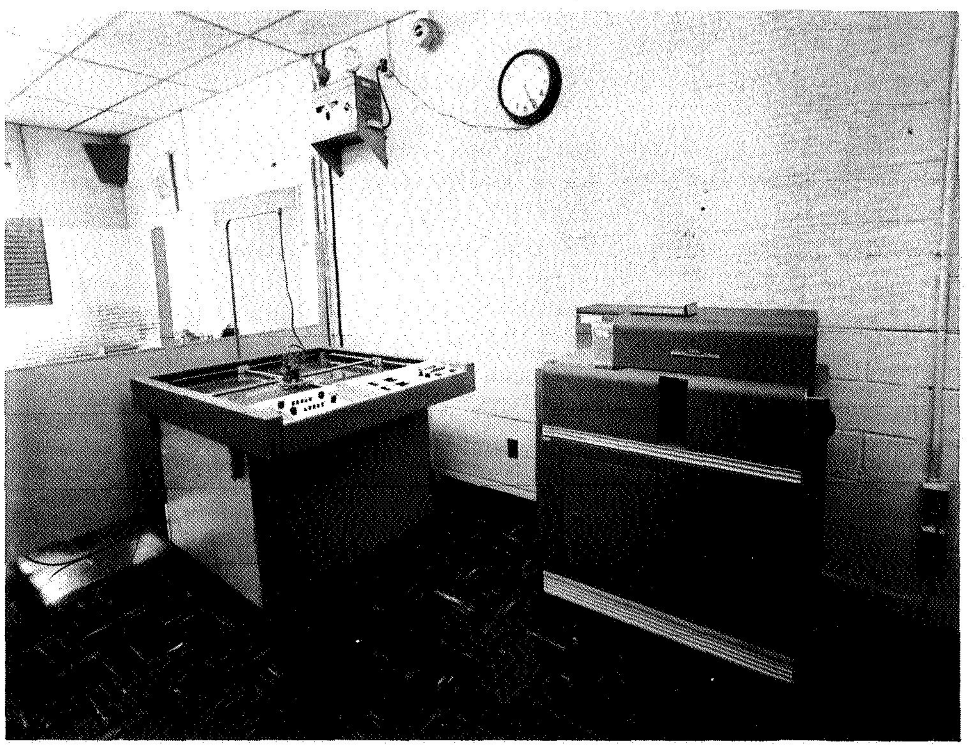


FIGURE 28. AUTOMATIC DATA PLOTTER

Data Presentation. The project engineer or representative is furnished one copy of the raw data as soon as it is printed after each run.

The data are reduced as soon as possible, and one copy of the reduced data is transmitted directly to the project engineer. The time required for data reduction varies, depending upon the type of test, the number of components, and the number of data points. For standard programs, reduced data will be available on the following working day. Pressure data are normally presented as either local pressure ratios (P/P_o) or pressure coefficients (C_p). Force data are reduced to conventional coefficient form. Typical printouts are shown in figure 29.

THE RESPONSIBILITY OF THE TUNNEL USER

Once initial contact has been made, a decision for a feasibility conference will be made based on the complexity of the test. When the test has been deemed feasible by the Gas Dynamics Section, the user will be required to submit an MSFC Form 197, "Request for Aerodynamic Testing," shown in figure 30. The information thus supplied will enable schedules to be set and necessary pre-test work to begin.

After a test has been firmly scheduled, the user should furnish the tunnel the following information at least three weeks before the test date:

(1) Three complete drawing sets
(2) Two copies of stress reports
(3) Ten copies of the pre-test report.

Model drawings should include detailed drawings with material and heat treatment designations of each model and sting part and sufficient assembly drawings to show the external model shape, the balance and sting attachment, clearances, and the tunnel installation.

The stress report should contain a detailed analysis of the model and mounting hardware, and should be made so that critical sections can be located and checked. Analysis should be based on the running or starting load, whichever is the largest. A minimum safety factor of 4.0 based on ultimate strength is required. Any deviations shall require the advance approval of the facility manager.

The pre-test report shall be a complete compilation of the requirements of the test and should include at least the following items:

1. Introduction.

2. Title of program.

3. Security information for the model, the test data, and the final data report.

4. Purpose and scope of test.

5. Model description - dimensional details, model installation sketches, references, configuration nomenclature.

6. Model load estimate - maximum load conditions, center of pressure, curves of any similar known configuration or estimated characteristics.

7. Facility operating conditions - pressure levels, angle-of-attack ranges, Mach numbers, Reynolds numbers, etc.

8. Facility mounting hardware - to be furnished by the user, to be furnished by the facility.

9. Special equipment requirements - photographic coverage, flow visualization, model fouling indicators, pressure instrumentation, auxiliary air, auxiliary electrical power, hinge moments, etc.

10. Estimated facility occupancy - installation, running, model changes, removal.

11. Data to be recorded during tests - configuration,Mach number, six-component force data (N, A, PM, etc.), base pressures, local model pressures, tunnel operating conditions, etc.

12. Data reduction - model reference areas and lengths, moment reference position, definition of aerodynamic coefficients (e.g., $C_N = N/qS$ body axis), reference axis transfer equations, etc.

13. Data presentation - data to be tabulated and order of tabulation desired, and where and to whom the data should be delivered.

14. General - names,addresses, and phone numbers of the personnel who will participate in the test and their tentative arrival dates, shipping instructions for return of the model and other equipment, etc.

15. Tentative run schedule.

The test hardware and equipment should be delivered to the Facility Manager as early as possible and at least two weeks before testing. Additional time may be requested for complex tests.

TEST	RUN/R	FR	α-COR	CM	CZ	CA	CAB	CAF	CM/CZ	Q	PTA	PSA	R/L	M
2284	511/0	1	-4.18	-0.00886	-0.06357	0.87056	0.48594	0.38461	0.13936	7.188	21.458	12.693	6.16	0.900
2284	511/0	2	-3.16	-0.00663	-0.04881	0.87709	0.49438	0.38270	0.13589	7.175	21.465	12.724	6.15	0.898
2284	511/0	3	-2.16	-0.00473	-0.03295	0.88117	0.49466	0.38651	0.14346	7.186	21.465	12.704	6.15	0.899
2284	511/0	4	-1.65	-0.00386	-0.02418	0.88542	0.49810	0.38731	0.15940	7.183	21.458	12.701	6.15	0.899
2284	511/0	5	-1.12	-0.00264	-0.01634	0.88944	0.50250	0.38694	0.16145	7.182	21.469	12.716	6.13	0.898
2284	511/0	6	-0.63	-0.00173	-0.00901	0.89125	0.50659	0.38466	0.19190	7.185	21.477	12.720	6.13	0.898
2284	511/0	7	-0.12	-0.00062	-0.00107	0.89529	0.50613	0.38917	0.58504	7.161	21.442	12.720	6.11	0.897
2284	511/0	8	0.37	0.00080	0.00741	0.89409	0.50336	0.39073	0.10744	7.193	21.462	12.689	6.13	0.900
2284	511/0	9	0.90	0.00191	0.01517	0.89587	0.50817	0.38770	0.12597	7.178	21.450	12.701	6.10	0.899
2284	511/0	10	1.39	0.00323	0.02308	0.89596	0.50645	0.38951	0.13984	7.195	21.458	12.681	6.11	0.900
2284	511/0	11	1.92	0.00400	0.03178	0.89716	0.50609	0.39107	0.12588	7.184	21.446	12.685	6.10	0.900
2284	511/0	12	2.94	0.00618	0.04810	0.89095	0.50447	0.38648	0.12839	7.215	21.481	12.674	6.11	0.902
2284	511/0	13	3.96	0.00826	0.06440	0.88454	0.49552	0.38902	0.12821	7.221	21.465	12.646	6.09	0.903
2284	511/0	14	6.01	0.01266	0.09688	0.86380	0.47947	0.38433	0.13088	7.204	21.462	12.670	6.09	0.901
2284	511/0	15	8.03	0.01740	0.13078	0.83337	0.45979	0.37358	0.13307	7.193	21.438	12.662	6.09	0.901

TEST	RUN/R	CM/OC	CZ/OC	LEAST SQUARES SLOPES FOR FR 3-11	CM/CZ	Q-AVG	PTA-AVG	PSA-AV	R/L	M-AVG
2284	511/0	0.00222	0.01573		0.14112	7.189	21.460	12.692	6.12	0.900

Q-AVG	PTA-AVG	PSA-AV	R/L	M-AVG
7.189	21.460	12.692	6.12	0.900

TEST 2273 RUN 30/0 ALPHAC -8.02 ROLL 0.00

X/D	OR-ANG	CP	PTA	PSA	QA	M
0.497	0.00	0.0042	21.469	12.322	7.414	0.927
0.497	15.00	-0.0026	21.469	12.322	7.414	0.927
0.497	30.00	-0.0172	21.469	12.322	7.414	0.927
0.497	60.00	-0.0600	21.469	12.322	7.414	0.927
1.512	0.00	0.0231	21.450	12.356	7.381	0.924
1.512	15.00	0.0178	21.450	12.356	7.381	0.924
1.512	30.00	0.0063	21.450	12.356	7.381	0.924
1.512	60.00	-0.0356	21.450	12.356	7.381	0.924
2.498	0.00	0.0283	21.465	12.356	7.392	0.924
2.498	15.00	0.0241	21.465	12.356	7.392	0.924
2.498	30.00	0.0099	21.465	12.356	7.392	0.924
2.498	60.00	-0.0309	21.465	12.356	7.392	0.924
3.498	0.00	0.0247	21.458	12.399	7.362	0.921
3.498	15.00	0.0184	21.458	12.399	7.362	0.921
3.498	30.00	0.0063	21.458	12.399	7.362	0.921
3.498	60.00	-0.0326	21.458	12.399	7.362	0.921
3.748	0.00	0.0308	21.465	12.345	7.398	0.925
3.748	15.00	0.0261	21.465	12.345	7.398	0.925
3.748	30.00	0.0115	21.465	12.345	7.398	0.925
3.748	60.00	-0.0272	21.465	12.345	7.398	0.925
3.998	0.00	0.0303	21.458	12.325	7.404	0.926

TEST 2273 RUN 30/0 ALPHAC -8.02 ROLL 0.00

X/D	OR-ANG	P/PS	P/PT	PLA	QA	M
0.497	0.00	1.0025	0.5754	12.352	7.414	0.927
0.497	15.00	0.9984	0.5730	12.302	7.414	0.927
0.497	30.00	0.9896	0.5680	12.194	7.414	0.927
0.497	60.00	0.9639	0.5532	11.877	7.414	0.927
1.512	0.00	1.0138	0.5840	12.527	7.381	0.924
1.512	15.00	1.0106	0.5822	12.488	7.381	0.924
1.512	30.00	1.0038	0.5782	12.403	7.381	0.924
1.512	60.00	0.9787	0.5638	12.093	7.381	0.924
2.498	0.00	1.0169	0.5854	12.565	7.392	0.924
2.498	15.00	1.0144	0.5839	12.534	7.392	0.924
2.498	30.00	1.0059	0.5791	12.430	7.392	0.924
2.498	60.00	0.9815	0.5650	12.128	7.392	0.924
3.498	0.00	1.0147	0.5863	12.581	7.362	0.921
3.498	15.00	1.0109	0.5841	12.534	7.362	0.921
3.498	30.00	1.0037	0.5800	12.445	7.362	0.921
3.498	60.00	0.9807	0.5667	12.159	7.362	0.921
3.748	0.00	1.0185	0.5857	12.573	7.398	0.925
3.748	15.00	1.0157	0.5841	12.538	7.398	0.925
3.748	30.00	1.0069	0.5791	12.430	7.398	0.925
3.748	60.00	0.9837	0.5657	12.144	7.398	0.925
3.998	0.00	1.0182	0.5849	12.550	7.404	0.926

FIGURE 29. SAMPLE PRINTOUT OF FINAL COMPUTER DATA

A pre-test conference is usually held two weeks before the test to resolve last-minute test details and to familiarize all personnel with the test. Data reduction requirements will also be firmed up during this time. Conferences will be scheduled by Mr. D. O. Cope and/or the Facility Manager.

All pre-test coordination whould be done through the Facility Manager or the person he designates. During the testing, the user should coordinate all test requirements through the operating contractor's facility engineer assigned to the test. It is necessary that the user have a qualified project engineer present at all times to monitor results and make necessary decisions concerning the conduct of the test.

Additional information may be obtained from the Chief, Gas Dynamics Section, Experimental Aerophysics Branch, Aerophysics Division, Aero-Astrodynamics Laboratory.

REQUEST FOR AERODYNAMIC TESTING			DATE:	
2. COST CODE:		3. FACILITY TO BE UTILIZED:		
4. PURPOSE AND SCOPE OF TEST:				
5. TYPE OF TEST:	6. MODEL CONFIGURATION:		7. MACH NUMBERS:	
8. STAGNATION PRESSURE, PSIA:	9. STAGNATION TEMPERATURE, °F:		10. ANGLE OF ATTACK RANGE, DEG.:	
11. ANGLE OF YAW RANGE, DEG.:	12. ROLL ANGLES, DEG.:		13. NUMBER & KIND OF MEASUREMENTS:	
14. MODEL LOAD ESTIMATES:	15. LOCAL PRESSURE MEASUREMENTS:		16. PHOTOGRAPHIC REQUIREMENTS:	
17. FLOW VISUALIZATION:	18. BALANCE NUMBER:		19. STING NUMBER:	
20. MODEL NUMBER:				
21. MISCELLANEOUS, INFORMATION:				
22. NAMES OF PERSONS PARTICIPATING IN TEST: TEST PROJECT ENGINEER			ORGANIZATION:	PHONE NUMBER:
23. SIGNATURE OF RESPONSIBLE CIVIL SERVICE PERSON:		DATE:	ORGANIZATION:	PHONE NUMBER:

TO BE COMPLETED BY S&E-AERO-AEG STAFF			
24. TEST NUMBER:		25. ESTIMATED TUNNEL OCCUPANCY:	
26. SCHEDULED TEST DATES:		27. REVISED TEST DATES:	
28. COMMENTS:			
29. APPROVALS			
SIGNATURE OF FACILITY MANAGER:	DATE:	SIGNATURE OF CHIEF, GAS DYNAMICS SECTION:	DATE:
30. TEST COMPLETED:		31. NUMBER OF RUNS:	
32. NOTES:			

MSFC - Form 197 (July 1971)

FIGURE 30. REQUEST FOR AERODYNAMIC TESTING

Any changes to existing tunnel performance or procedures as noted in this handbook will be issued to acknowledged recipients.

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APPROVAL

THE GEORGE C. MARSHALL SPACE FLIGHT CENTER'S
14 x 14-INCH TRISONIS WIND TUNNEL TECHNICAL HANDBOOK

by Erwin Simon

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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A. Richard Felix
Chief, Experimental Aerophysics Branch

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